UNU Desertification Series No. 8

WHAT MAKES TRADITIONAL TECHNOLOGIES TICK?

A REVIEW OF TRADITIONAL APPROACHES FOR WATER MANAGEMENT IN DRYLANDS

Edited by Zafar Adeel,
Brigitte Schuster and Harriet Bigas

What Makes Traditional Technologies Tick?
A Review of Traditional Approaches for Water Management in Drylands

What Makes Traditional Technologies Tick?
A Review of Traditional Approaches for Water Management in Drylands

Edited by

Zafar Adeel, Brigitte Schuster and Harriet Bigas

UNU-INWEH

Disclaimer

The designations employed and presentations of material throughout this publication do not imply the expression of any opinion whatsoever on the part of the United Nations University (UNU) concerning legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The views expressed in this publication are those of the respective authors and do not necessarily reflect the views of UNU. Mention of the names of firms or commercial products does not imply endorsement by UNU.

Cover Photo Credits

1. Orchids irrigated by a karez system, Pakistan. Photo courtesy of Faisal Farooq Khan.
2. A falaj in an Oman village. Photo courtesy of Abdullah S. Al-Ghafri.
3. Construction of a khattara in Morocco. Photo courtesy of Keiko Oshima.
4. The mountain step terraces of Yemen. Photo courtesy of Najib M.A. Al-Ghulaibi.
5. A water channel connecting a karez to a farm, Pakistan. Photo courtesy of Faisal Farooq Khan.
6. A karez in the Turpan Depression, China. Photo courtesy of Qingwei Sun on behalf of George Steinmetz.

Available from:

United Nations University
International Network on Water,
Environment and Health (UNU-INWEH)
175 Longwood Road South, Suite 204
Hamilton, Ontario L8P 0A1
Canada
Tel: +1 905 667 5511
Fax: +1 905 667 5510
E-mail: contact@inweh.unu.edu
Web: www.inweh.unu.edu

ISBN 92-808-6003-8

Contents

Preface

This unique book contains work by a group of dedicated young scholars who have been supported by a generous donation from the Blucker Fund. I would like to take this opportunity to express our sincere thanks to Mrs. Julie Blucker and Mr. Makoto Hiratsuka, whose support and encouragement has enabled these young scholars to study traditional hydro-technology in drylands.

As a geographer by academic training, I am always interested in learning from local people living in drylands. Over the past 50 years I have visited many different dryland areas while continuing my own comparative studies of foggara oases. I have had many chances to observe advanced, alternative and traditional (indigenous) technologies used in drylands. In that sense, the people of drylands are my teachers, instructing me how inhabitants can adapt to harsh environments and to manage issues associated with water scarcity.

Reviewing this half a century of my professional life spent in conducting research in drylands, I realize that my commitments as a faculty member have always made it difficult for me to spend sufficient time in the field. It is, therefore, opportune that these Blucker Fund fellowships have given a number of young scholars the possibility to conduct his or her research in developing countries, working closely with local communities. These scholars have become well acquainted with local manners, customs and languages in the field.

Water is a key challenge in drylands. From the prehistoric age up to the present, people have invented various technologies to catch and use water, either as rainwater, surface water, ground water or even as moisture from condensation. In ancient times, impressive hydraulic structures such as the Marib dam in Yemen and the Sennacherib Aqueduct in Mesopotamia were constructed to provide water for people in water-scarce areas. In the Syrian desert, the Harbaqa dam provided flood water irrigation during Roman times. These large dam systems eventually fell out of use many years ago, leaving only historical accounts and archaeological ruins.

On the other hand, we also have good examples of the continuous adaptation of traditional technology in drylands. An example is the Qanat system, variations of which are known as Foggara, Karez, Khattara or Aflaj. The Qanat system was probably invented around 3,000 years ago in Northern Persia or the Caucasas, and was used in Iran, Afghanistan, Arab countries, North Africa and China. In those countries, there is some renewed interest in this old system of underground channels, due to its energy efficiency (relying on the use of gravity) and prevention of over-extraction of groundwater (based on a system that cannot mechanically pump water from a sunken groundwater table).

Despite their sustainability and adaptation to dryland conditions, the need for continuous hard labor to maintain such traditional systems does not attract young researchers. Many traditional water management systems have fallen into disrepair. In order to address this dilemma, the introduction of new technology has been studied, and revived systems are now operating well in some countries.

Information about these innovations is not well disseminated amongst researchers, decision makers and local leaders. However, during the past several years, signs of improvement are visible in a number of countries. In 2000, the Iranian government organized an International Conference on Qanat in collaboration with the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations University (UNU) and other selected international and national institutions. Based on the Yazd Declaration of this conference, an International Qanat Research Center was established in Iran in 2004. Already, the center has published an excellent summary of 18 elderly Muqqanis' (traditional qanat technicians) oral descriptions of their experiences. In Xinjiang, China, the Xinjiang Karez Research Society published a complete inventory of Karez in Xinjiang. This is a good example for other countries because they include not only scientific and technical data, but also historical information. In Algeria, the Office National des Resources Hydrauliques published a complete, GIS-based inventory of all foggara of the Wilaya d'Adrar.

The above mentioned approach to reinstate and update traditional hydro-technology began at the beginning of the 21st century. The future generations should follow the direction of this revived international attention to traditional technology. It is interesting to note that the United Nations Convention to Combat Desertification (UNCCD) is also interested in the role of traditional technology in combating desertification. In parallel to these trends, a Traditional Knowledge World Bank was established through support from UNESCO and the Toscana Government of Italy to provide existing data on the Internet.

We are now living on our planet together and facing global environmental problems such as climatic change, desertification and serious energy shortages. Our ability to ensure quality of life for us and for future generations depends how we use precious water resources. I believe that traditional hydro-technology is an excellent topic to be seriously pursued by future young researchers and decision makers. To ensure our future, we need a harmonious network to think and work together on this topic across the national boundaries.

Prof. Iwao Kobori
Senior Advisor
United Nations University

March 2008

Acknowledgements

The research work presented in this book has been made possible by the Blucker Fund. The United Nations University is grateful to Ms. Julie Blucker for providing funding for this purpose, and to Mr. Makoto Hiratsuka for providing support for the Blucker Fund.

The information presented in this book has been made possible through dedicated work of the researchers supported by the Blucker Fund. Each of these researchers worked closely with communities in their respective research sites. We owe gratitude to these communities for lending their support to the research work, and for being part of the effort to revive and revitalize the use of these traditional technologies.

Promoting Traditional Water Management in Drylands: Adapting Traditional Knowledge to Meet Today's Challenges

Zafar Adeel

Introduction

Management of scarce water resources is a major challenge for people living in drylands (please see box for a definition of drylands). Over the centuries, dryland dwellers have overcome this challenge through traditional methods of water harvesting and management, which have ensured long-term sustainability of water resources through demand management and adequate resource replenishment. In general, these methodologies – despite being effective and cost-efficient – are either in decline or have been completely abandoned. Building up on previous work undertaken within the United Nations University (UNU) on dryland management, UNU launched an initiative in 2001 to specifically address the research needs and to evaluate the current status of traditional water technologies in drylands around the world. This chapter provides the context for the studies presented in this book and describes how it has helped develop a better overall understanding of the traditional water management technologies, and in doing so, brought greater international attention to this field of science.

> ***Drylands** include all terrestrial regions where the production of crops, forage, wood and other ecosystem services are limited by water. Formally, the definition encompasses all lands where the climate is classified as dry sub-humid, semi-arid, arid or hyper-arid. This classification is based on the values of Aridity Index, which is defined as the long-term mean of the ratio of an area's mean annual precipitation to its mean annual potential evapotranspiration (Adeel et al., 2005).*

Water Challenges in Drylands Management

Drylands are unique in their dependency on relatively scarce available water – this scarcity exists on a gradient ranging from mild in dry sub-humid areas to extreme in hyper-arid areas (or deserts), and adversely impacts the land productivity. Limited by the availability of water, there are quite profound impacts on how the human societies based in drylands relate to their environment and balance the tradeoffs in land and water use. These tradeoffs often create competition, and sometimes conflict, between different riparian users; for example, farmers and pastoralists also often compete for water use. Over the millennia, dryland societies thriving in these settings have adopted sustainable and equitable approaches for managing their water as well as other natural resources. Today, water management in drylands is under a serious paradigm shift in the face of new challenges and driving forces.

The most significant of these challenges is desertification (please see box for the definition of desertification), which hampers the achievement of sustainable development and natural resource management in drylands. Desertification is closely linked to management of water resources, agricultural and rangeland management approaches, climate change processes and changes to vegetation cover and biological diversity. The magnitude and impacts of desertification vary from place to place and change over time. This variability is driven by the degree of aridity combined with the pressure people put on the ecosystem's resources as shown in Figure 1. As water availability increases 200 m^3 per person per year in hyper-arid areas to ca. 3,000 m^3 in dry sub-humid areas, density of human population also increases ca. 10 per km^2 to ca. 70 per km^2, respectively. A similar pattern for livestock density also exists, and is related also to the stress patterns in drylands. As a result, the maximum population stress is found in drylands that are relatively abundant in water, i.e., semi-arid regions.

***Desertification** is defined as the land degradation in drylands resulting from various factors, including climatic variations and human activities. Land degradation is, in turn, defined as the reduction or loss of the biological or economic productivity of drylands. The Millennium Ecosystem Assessment (Adeel et al., 2005) has argued that measurement of persistent reduction in the capacity of ecosystems to supply services provides a robust and operational way to quantify land degradation and desertification.*

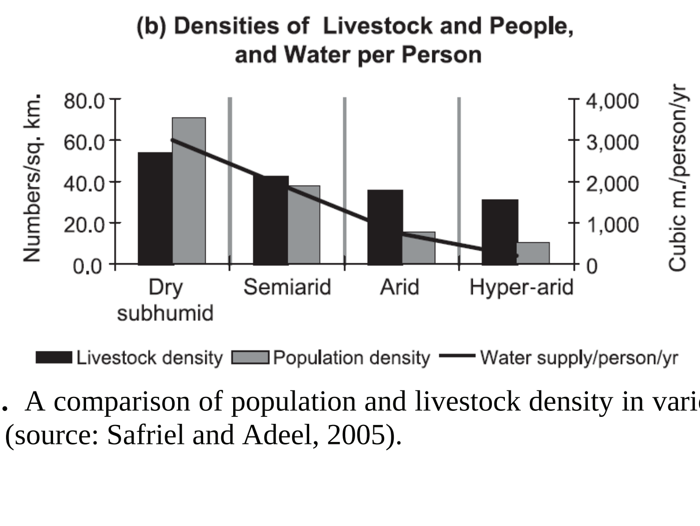


Figure 1. A comparison of population and livestock density in various dryland subtypes (source: Safriel and Adeel, 2005).

There are consistent global manifestations of the impacts of desertification in terms of the well-being of people living in dryland developing countries. A global evaluation report on desertification developed by the Millennium Ecosystem Assessment (MA) has helped us better understand the nature and impacts of desertification (Adeel et al., 2005). The MA report has determined that growing desertification in drylands – which occupy over 41 percent of the world's land area and are home to over two billion people – threatens the homes and livelihoods of millions of poor.

These impacts of desertification on dryland populations are further exacerbated by political marginalization of the poor and the slow growth of health and education infrastructures. For example, the MA report shows that infant mortality in drylands in developing countries averages about 54 children per 1,000 live births, ten times higher than that in industrial (OECD[1]) countries, as shown in Figure 2. The hunger rates in children under the age of five in drylands demonstrate a clear linkage to food insecurity as well as the level of aridity. As mentioned earlier, it can be argued that semiarid areas are worse off in terms of human well-being as a result of a high degree of sensitivity and pressure, which also generate the highest degree of land degradation. The region-to region variability is also significant, in which the Gross National Product (GNP) per capita in OECD dryland countries exceeds that of dryland countries in other regions almost by an order of magnitude. This is not surprising, considering that economic performance relates to many other governance and macro- and micro-economic factors. Thus the economic status of dryland societies is not entirely linked to the low availability of basic ecosystem services such as water and biological productivity.

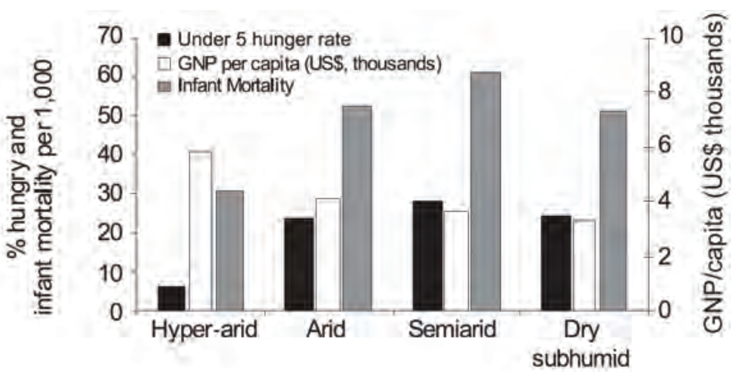


Figure 2. Human well-being statistics for drylands (source: Safriel and Adeel, 2005).

Evaluation of future development scenarios by the MA shows that if these present trends in land and water use continue unchecked, the global extent of desertified areas will likely increase. It is also projected that population growth

[1] The Organisation for Economic Co-operation and Development (OECD) currently consists of a group of 30 member countries that have ratified the Convention of the OECD (further information on the OECD is available at http://www.oecd.org).

and increase in food demand will drive an expansion of cultivated land, often at the expense of woodlands and rangelands (Adeel et al., 2005). The MA report also highlights the global and transboundary nature of the desertification challenge. The adverse impacts of desertification on the global environment – such as increasing dust storms, floods and global warming – are well known and documented. There are also alarming impacts of desertification on societies and economies, as shown in Figure 2. These impacts are directly related to human migration and economic refugees.

On a more positive note, numerous adaptive and corrective approaches for natural resource management are available to match the degree of aridity and other local constraints. These approaches – with underlying integration of land and water management – can help protect and restore the capacity of the dryland ecosystems to provide key benefits and services. In this respect, communities – and their knowledge of the ecosystems around them – can play a central role in the adoption and success of effective land and water management policies. Needless to say, they need support in the form of institutional and technological capacity, access to markets, and financial capital. On the whole, prevention through community-based efforts is a much more effective way to cope with the dryland challenges, because any subsequent attempts to rehabilitate desertified areas are costly and tend to deliver limited results.

Efforts to meet the drylands challenges will typically yield multiple local and global benefits, and help mitigate other major environmental issues like human-induced global climate change and loss of biological diversity. Such efforts are also critical and essential for successfully meeting the Millennium Development Goals – particularly those related to poverty reduction. The possibility of long-term success is much greater when these sustainable land/water management approaches are linked to providing dryland people viable livelihoods and utilizing their social capital in the form of traditional knowledge.

Significance of Traditional Approaches in Drylands Management

Human societies in drylands have learnt to cope with water scarcity, and often developed these management approaches in close overlap with social and cultural evolution. As a consequence, traditional knowledge (please see box for detailed description of traditional knowledge) has two salient features; it leads to practices that are: (a) socially acceptable; and (b) linked to sustainable utilization and management of natural resources. The latter point is particularly crucial for drylands where sustainability of water resources – in the face of inherent scarcity, wide-ranging fluctuation on a seasonal and annual basis and potential conflicts and competition amongst users – is a matter of life and death. Traditional methods of water harvesting and management overcome this challenge by following sustainable management of water resources.

As a good example of such traditional management approaches, oases demonstrate the appropriate usage of the physical and geomorphological factors around oases (Safriel and Adeel, 2005). In general, oases encompass a water distribution and management system, planting structure that helps regulate a micro-climate, cultivation of plants that are tolerant of aridity and salinity, waste recycling systems, and sand dune stabilization techniques.

> ***Traditional Knowledge** refers to the knowledge, innovations and practices of indigenous and local communities around the world. Developed from experience gained over the centuries and adpated to the local culture and environment, traditional knowledge is transmitted orally from generation to generation. It tends to be collectively owned and takes the form of stories, songs, folklore, proverbs, cultural values, beliefs, rituals, community laws, local language, and agricultural practices, including the development of plant species and animal breeds (United Nations Convention on Biological Diversity – UNCBD).*
>
> *Traditional knowledge is information, skills, practices and products – often associated with indigenous peoples – which is acquired, practiced, enriched and passed on through generations. It is typically deeply roooted in a specific political, cultural, religious and environmental context, and is a key part of the community's interaction with the natural environment (IISD, 2003).*
>
> *Traditional knowledge itself has a number of different subsets, some of them designated by expressions such as "indigenous knowledge", "folklore", "traditional medicinal knowledge" and others. Contrary to a common perception, traditional knowledge is not necessarily ancient. It is evolving all the time, a process of periodic, even daily creation as individuals and communities take up the challenges presented by their social and physical environment. In manay ways, therefore, traditional knowledge is actually contemporary knowledge. Traditional knowledge is embedded in traditional knowledge systems, which each community has developed and mantained in its local context (World Intellectual Property Organization – WIPO).*

Another striking example of a traditional water management system is "qanat" (also called Kanat or Karez in Asia, Foggara or Khettara in Northern Africa, and Falaj in the Arab world). It is an underground "engineered" water management system that has been employed as variants of the same technology for centuries in a number of countries in Northern Africa and Western Asia – as well as other Asian countries including Afghanistan, Iran, Pakistan and China. The management system, as shown in Figure 3, operates on the basis of utilizing a man-made gradient to draw water from aquifers. Water withdrawal in such traditional systems is (a) achieved under gravity and without application of an external power source; (b) minimizes evaporation losses because water storage and transport is mostly underground; and (c) can only withdraw water which is available in the aquifer through natural recharge, avoiding any over-exploitation of groundwater resources. This traditional technology is a particularly effective system considering the water scarcity, weather conditions and low-level technology generally available in this region. In communities working together to maintain these systems, long-term benefits can be enjoyed by all without a major capital investment and with nominal operation and maintenance costs.

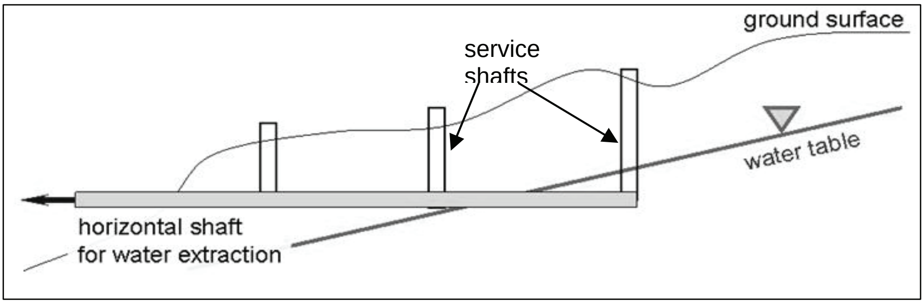


Figure 3. A schematic representation of a qanat water delivery system.

Another part of traditional water technologies are the locally adapted architectural innovations also used to facilitate water conservation by condensing atmospheric water, including stone heaps, dry walls, little cavities, and depressions in the soil, which allow plants to overcome periods of high drought (Laureano, 2003; Safriel and Adeel, 2005).

As most of the drylands around the globe are situated in developing countries, application and development of traditional knowledge and technologies for water management should ideally be encouraged. However, present trends indicate that use of these traditional water management technologies is falling by the wayside. There are four major reasons for this pattern.

First, changes in the socio-economic situation in these countries have typically meant that there are fewer skilled experts available to undertake development and management of these systems. As urban populations grow and rural-to-urban exodus continues, the manpower available for maintaining these primarily rural applications becomes limited. The social, cultural and economic implications of this change in water management approach are poorly understood; conversely, economic incentives – particularly to young entrepreneurs – to utilize these approaches are few.

Second, "newer" water supply solutions like electric-powered tube wells or irrigation systems based on water delivery through canal and channels may hold greater appeal for the general public for various reasons. While being less labor-intensive, the real cost of these alternative approaches is not obvious to the end-user. This is mainly because developing-country governments typically provide heavy subsidies for capital investment into these systems and for power supply for their operation. Furthermore, the concept of "real-cost pricing" is politicized in the context of water-as-a-human-right debate; thus precluding a more unbiased and rational cost-benefit analysis of traditional versus "new" technologies. The new approaches do not compare favorably against more traditional ones when all the costs are fully accounted for. Finally, the information dissemination by governments to the general public encourages the perception of these systems as archaic and outdated.

Third, very limited research effort has been undertaken to improve these traditional technologies to better cope with the stresses imposed as a result of population growth, desertification, and other external social and economic driving forces. Consequently, there are technical problems in adopting new materials such as concrete pipes for use in qanats and less labor-intensive maintenance technologies. There are also unresolved economic cost-benefit analyses in determining the best ways to meet water demands.

Fourth, at the international level – particularly with development and aid partners – investment into research, evaluation, maintenance and deployment of traditional technologies is virtually non-existent. The rhetorical emphasis on traditional knowledge and technologies has not led to a major investment of resources. One notable exception to this is the initiative "World Traditional Knowledge Bank," which has systematically focused on compiling data and information, and is supported by the European Commission.

Given the potential for sustainable management of water resources through the development and application of traditional water management technologies, one can argue that there should be a strategic and proactive investment in these technologies. Such a proactive approach is endorsed also in the MA report, which shows that coping with desertification and its related economic conditions will likely fare better when proactive management approaches are used.

Contributions by the United Nations University

The United Nations University has aimed to help developing countries resolve the pressing global problems through capacity building and policy-relevant research. In this context, the challenges faced as a result of desertification and water scarcity in drylands have featured centrally in its activities. Building up on previous work undertaken within UNU on dryland management, UNU launched an initiative in 2001 to specifically address the research needs and to evaluate the current status of traditional technologies. This initiative was funded through the generous financial support of a philanthropist, Ms. Julie Blucker. It provided limited research grants to young researchers who were working with local communities to better understand their problems and help bring scientific rigor to problem-solving.

The objectives of this initiative were four-fold.

First, the initiative aimed to better understand and demonstrate the importance of traditional water management systems through focused research and field activities. In order to do so, a number of subprojects explored the comparative evaluation of these systems in different geographic and environmental settings.

Second, the initiative aimed to understand in a scientific manner the relationship between local communities and the management of traditional water systems. This evaluation was done with the view that traditional knowledge and technologies are not static but evolve in contemporary societies. The research projects focused on means and ways for improving traditional water management systems according to evolving socio-economic patterns.

Third, the initiative indirectly helped build the capacity of local researchers to undertake community-oriented field research; particularly highlighting South-South collaboration.

Fourth, there was an emphasis on raising public awareness on key issues pertaining to utilization of traditional water management technologies. This awareness-raising was extended to the international community through publications and international workshops.

Typically, each researcher demonstrated that their work was a part of an ongoing active research activity and involved *in situ* field work and was developed with due consideration given to community involvement. This sub-project deployment was done selectively, and based on dozens of applications that were received as a result of public advertisement about the project.

The project led to the deployment of sub-projects in key areas that are hubs of traditional water management technologies, such as rural Syria, mountain-terraced Yemen, North Africa, Omani desert and Pakistani hilly drylands. Many of the researchers engaged in the initiative undertook the research work as part of their graduate studies. This engagement, therefore, enabled them to further the research capacity in the respective local settings, and to personally achieve higher academic qualifications. As the initiative was designed to link directly with the local communities, in many cases it provided the additional incentive for the researcher to develop stronger ties with the respective communities. This has clearly been the case in Tunisia, where the researcher (Dr. Mohammed Ouessar) is now running a strong NGO to help explore new livelihoods (Ouessar et al., 2003). Similarly, in Oman, the researcher (Prof. Abdullah Al-Ghafri) has accepted a faculty position after the conclusion of his graduate programme (Al-Ghafri et al., 2003).

There are also some indications that the subprojects and their respective lead researchers have helped develop a better overall understanding of the traditional water management technologies, and in doing so, brought greater international attention to this field of science. Subsequently, they emerged as leaders in traditional technologies, and helped set up professional networks and continued research beyond the scope of the project.

Outlook: The Future of Water Management in Drylands

The projections of water availability and quality of freshwater worldwide, and particularly in drylands, do not present a positive picture. In many cases, the dryland areas are anticipated to get drier (Ezcurra, 2006); these include areas in Western Asia, Sub-Saharan Africa and Atacama desert, which have already and will continue to experience a decrease in precipitation as a result of global climate change. Those climatic impacts, when overlaid with increasing population-related stresses and other anthropogenic impacts on water quality, mean a likely drastic decrease in water availability in the next few decades.

The global water challenge has far more severe ramifications for drylands than any other ecosystem (Adeel et al, 2005). In drylands, the rural dwellers are particularly vulnerable. At the same time, there is greater room for innovation in water resource management and provision in rural settings. A combination of traditional technologies with non-renewable energy sources can bring new alternatives for livelihoods. Implementing such innovations poses challenges in terms of enhancing the capacity to understand and implement; both are often hampered by lack of research and lack of financial resources, respectively.

It is hoped that the work presented in this publication will contribute up to the innovative solutions and enhancements to traditional technologies. As stated earlier, traditional knowledge is not static and stuck in history, rather it is dynamic and continuously evolving. It can certainly benefit from scientific rigor, combined with a South-South exchange of information and ideas. The circle can be completed by linking it to the local communities and integrating it with alternatives for sustainable livelihoods.

References

Adeel, Z., U. Safriel, D. Niemeijer, R. White, G. de Kalbermatten, M. Glantz, B. Salem, B. Scholes, M. Niamir-Fuller, S. Ehui, and V. Yapi-Gnaore (2005) Ecosystems and Human Well-being: Desertification Synthesis, a Report of the Millennium Ecosystem Assessment, World Resources Institute, Washington DC, USA.

Al-Ghafri, A., T. Inoue, and T. Nagasawa (2003) “Irrigation scheduling of aflaj of Oman: Methods and its modernization” in Adeel, Z. (ed.), Sustainable Management of Marginal Drylands: Application of Indigenous Knowledge for Coastal Drylands, Proceedings of a Joint UNU-UNESCO-ICARDA

International Workshop, Alexandria, Egypt, 21-25 September 2002. United Nations University, Tokyo, Japan.

Ezcurra, E (ed) (2006) Global Deserts Outlook, United Nations Environment Programme, Nairobi, Kenya.

IISD (2003) “Traditional Knowledge and Patentability,” IISD Trade and Development Brief No. 7, International Institute for Sustainable Development, Winnipeg, Canada.

Laureano, P. (2003) “A history of traditional water management technologies” in Adeel, Z. (ed.), Sustainable Management of Marginal Drylands: Application of Indigenous Knowledge for Coastal Drylands, Proceedings of a Joint UNU-UNESCO-ICARDA International Workshop, Alexandria, Egypt, 21-25 September 2002. United Nations University, Tokyo, Japan.

Ouessar, M., M. Sghaier and M. Fetoui (2003) “Comparison of traditional and contemporary water management systems in the arid regions of Tunisia” in Adeel, Z. (ed.), Sustainable Management of Marginal Drylands: Application of Indigenous Knowledge for Coastal Drylands, Proceedings of a Joint UNU-UNESCO-ICARDA International Workshop, Alexandria, Egypt, 21-25 September 2002. United Nations University, Tokyo, Japan.

Safriel, U. and Z. Adeel (2005) “Dryland Systems” in Hassan, R., R. Scholes and N. Ash, (2005) Ecosystems and Human Well-being: Current State and Trends, Volume 1, Island Press, Washington DC, USA.

Assessment of Three Collective Renovations of Traditional Qanat Systems in Syria

Joshka Wessels

Introduction

In the summer of 2000, a small group of Syrian villagers renovated and cleaned their own common water source with international help. The water source is an ancient Byzantine water tunnel system called qanat. This was a pilot renovation, and two subsequent renovations took place in the south and south-western parts of Syria during 2001 and 2004, respectively. This work raised some interesting questions: In this time of ecological farming and increasing environmental awareness, is it possible to re-use an ancient water supply system? And what policy criteria could be used to assess feasibility? We used a unique approach in feeding back field data to the local communities, with edited video footage of qanat renovations and interviews of qanat users.

Study Area

Syria is located at the eastern part of the Mediterranean Sea between Lebanon and Turkey. The country's climate comprises dry hot summers with mild winters and rainy spells in autumn and winter. The population is ca. 19 million people with a growth rate of 2.3 % (2006 estimate). The main language is Arabic and the population consists of various ethnic groups of which Arabs form the majority (90.3%). The main religion is Sunni Islam (74%), 10% is Christian and the rest are other Muslim sects.

Water is the main limiting factor for agriculture in Syria. Through ingenious water extraction techniques, ancient peoples like Persians and Romans coped with the dry climate. One of the techniques is called qanat, a subterranean tunnel that taps the groundwater and leads it artificially to a human settlement and agricultural lands using gravity flow conditions (Lightfoot, 1996; Beaumont *et al.*,1989). This chapter presents practical efforts on how collective community action renovated qanats. We look at four case study sites in Syria; Shallalah Saghirah in the north-west, Arak in the centre, Qara and Dmeir both located in the southwest.

Shallalah Saghirah is a small village located 70 km from the northern city of Aleppo towards the Syrian desert. It consists of some 25 households. The village did not have electricity at the time the fieldwork was conducted, educational levels are low, the schoolteacher from Aleppo rarely visits the school building to teach the children, and there is public transport available only on request (Wessels, 2003 a & b).

Qara lies at the foot on the eastern side of the Anti-Lebanon Mountains near the border between Syria and Lebanon. The site contains 10 qanats of which five are still running. The qanats are regularly maintained and upgraded by the Directorate of Irrigation of the Awaj/Barada basin. The qanats are situated outside the urban settlement on a straight line running from North to South and show little decrease in flow.

Dmeir is a medium-sized town situated in the dry area on the borderline between the suburbs of Damascus and the Syrian steppe. The site has three running qanats. They have a traditionally developed rights and regulation system. The flow of the qanats seemed to be consistent and one of the qanats even increased after a small earthquake in 1992.

Arak is a village located in the centre of Syria. Arak lies some 20 km east of the famous town of Palmyra in the middle of the Syrian steppe. It is very dry and the site knows three qanats of which two are still running. The community does not regularly maintain the qanats.

The Abandonment of Qanats

Generally, a qanat system consists of an underground part and a part above ground surface. The underground part is divided into the “water production section” and the “water transport section”. In the “water production section”, the water is collected, either from a natural source or through infiltration of groundwater. This section is underneath the groundwater level of the surrounding area. The “water transport section” transports the water to the surface. This section is usually lined with plastering on the sides to prevent leakage of water. The gradient of the tunnel is very precise and should not exceed 5% in order not to let the flow erode the rock or sand in which the tunnel is dug (Goblot, 1979). On the other hand, the gradient should not be too low because then the water cannot be transported to the surface (ibid.).

By nature, a qanat is a truly sustainable technique of extracting groundwater. It only relies on gravity and it cannot exhaust or over-exploit an aquifer. The technique is thought to originate from Old Persia (present day Iran) around 3,000 years ago (Beaumont et al., 1989; Goblot, 1979). In the Arab world, the ancient tunnels systems can be found in an area spanning from Iraq to Morocco and from Syria to Oman. They have different names, for example “Foggara” in

Algeria and Morocco or “Falaj” in Oman. Qanats are not dug anymore because of the dangers that accompany the digging; a lot of traditional qanat diggers are reported to have died during construction. There are only approximately 40 traditional qanat diggers (muqannis) left in Iran, for example.

Qanat systems are increasingly drying up and being abandoned throughout the Middle East and North African region. Modern development, population growth and changing socio-economics force users to change their lifestyle to one based on agricultural self-sufficiency as well as on other non-agricultural income sources (Wessels, 2003; Lightfoot, 1996; Beaumont et al. 1989). With these societal transformations, users lose interest and look for modern techniques of water supply. Diesel operated or electric-powered motor pumps frequently replace qanats. Consequently, the falling groundwater tables affect qanats, until they finally dry up. But the problem is not only technical; the younger generation pulls towards the cities and finds jobs other than farming. This group of youngsters literally abandons qanats. With the abandonment of qanats the indigenous knowledge and collective action critical for qanat upkeep also disappear.

Qanats in Syria

In 2000-2001, an ICARDA team conducted a reconnaissance survey in Syria guided by a map prepared by researchers from Oklahoma State University (USA) in 1994. We documented geographical, socio-economic, and hydrological characteristics and interviewed local experts and officials from various institutions. We found a total of 42 sites containing 91 qanats, of which 30 were still in active use. Others were dry or drizzling and almost abandoned. We assume that more qanats existed in the past but these were difficult to re-locate and beyond repair.

In Syria, the concentration of running qanats is around Damascus, Homs and in the steppe areas. The qanats used to provide the main water supply for drinking water and agriculture. Through circumstantial evidence we found that Syrian qanats were already in use during the Roman times. The digging technique and type of the qanats varies considerably throughout the country. In general, there are two types of qanats:

1. *Infiltration qanats*: In areas where the surface is flat, for example in the steppe (badia), the qanats can be long (more than 3 km) and dug into limestone rock or sandy soil. These qanats are based on groundwater infiltration from an alluvial fan or floodplain sometimes supported by natural sources in karstic holes. The walls of these tunnels are usually plastered with extra casing made of brick walls. This type of qanats is vulnerable to climatic factors, needs intensive maintenance and often collapses during floods and is consequently abandoned.

2. *Spring qanats*: Another type of qanat is located in the hills and mountains. This type is dug in hard rock or limestone and is in general short (not exceeding 3 km of length). This type bases its water supply on natural sources and infiltration of groundwater from the hills or mountains. Most of them have casings of airshafts or some plastering of the walls. Lastly, there are unique qanats that are located on the fringe of the steppe, tapping from natural springs that might even be sulphuric. Spring qanats are less subject to floods and collapsing, however, regular maintenance is a condition for keeping them running.

The water of Syrian qanats is used mainly for irrigated agriculture. The division of the water is based on its own local system of rights and regulations. Each user household has an irrigation share measured in time, the so-called “dor” (turn). This turn can last as little as 14 minutes or as much as one or two days, depending on how much land and water rights the particular household owns. The regulation system is based on a fixed amount of rotation in days in which all households with user rights have their turn. This rotation is called “addan”. Ideally, all land in the irrigated garden (bustan) should be irrigated within this “addan” but usually only some parts are irrigated either in summer or winter depending on the crops. The differences in “addan” for each qanat depend on many factors. Mainly it depends on the number of first users, the discharge of the qanat water, type of soil, type of main crops, and the total land surface. In some cases this might mean that the fixed “addan” has been there since the qanat has been dug, maybe even since Roman times.

Irrigation shares can be traded and are usually attached to land. In the past, a father would try to gain as much land and water shares as possible to divide a fair amount of each among his eldest sons. In this way, the land and water share would stay within the same family for decades or even centuries. Keeping the shares within the family is still very important. For example, if a farmer in Arak decides to leave his farm and start a business in Palmyra or Damascus, he could sell his land with attached water shares to his cousin. However, many farmers arrange for a caretaker for their shares when they leave their farm. In this way, they can always come back to their original land.

In each community, there are families with the biggest irrigation share who are represented in a committee that governs the qanat use and division of the water shares. There is usually also a so-called “natour”, a guard that makes sure that the shareholders get their rightful amount of water. The water shareholders pay a yearly amount to the committee from which the salary of the “natour” is paid and which forms a budget for maintenance and repair. When a committee or natour is not established, it is difficult for the community to maintain the upkeep of their qanat on a regular basis. In some of these cases, governmental assistance is given.

Already in early 1990s scientists came to the conclusion that qanats are being abandoned as water tables fall and qanat galleries go dry (Lightfoot, 1996). A valuable cultural heritage is vanishing. But the traditional technology can be combined with modern technology. In Qara, we have seen that combining ancient qanats and modern drip irrigation systems for fruit trees might prolong the life of some qanats and encourage younger generations to commit to their upkeep. Some farmers have their own reservoir, which is filled with water during their traditional turn. Attached to the reservoir is a modern drip irrigation system that waters extensive amounts of fruit trees. Another option to think of is to encourage eco-tourism based around qanats to provide alternative income for the farmers. As we have observed in countries like Oman, renovation of neglected qanats is possible.

Renovation Efforts with Qanat Communities

Four qanat sites were investigated between 1999 and 2003; at three sites (Shallalah Saghirah, Dmeir and Qara) major renovation activities took place between 2000 and 2004. We will briefly describe the process and results of these renovation efforts.

A pilot renovation was done in 2000 in Shallalah Saghirah; our team initiated a qanat cleaning based on the priorities and traditional knowledge of the community during focus group meetings with the village elders, the so-called "haqoun". The qanat is the only source of water in the village and dates back to the late Byzantine period, supported by the find of an oil lamp from this period. After some differences between the haqoun were settled, some young men became interested in renovation of the qanat. The haqoun made an informal written agreement among themselves to regulate the use, maintenance and renovation of the qanat. They selected a young village supervisor and made a list of all the workers that would be available for the cleaning work. With this agreement and a technical workplan and budget, the committee and the researchers initiated a search for funds necessary for cleaning and renovation. From June until September 2000 the renovation took place in Shallalah Saghirah with funds from the German and Dutch Embassies in Damascus. The workers were qanat users and all blood-related. A representative of the Aleppo Museum attended the worksite on a daily basis. The village supervisor was instrumental for motivating his fellow workers when disputes happened between them. However, an unsolved revenge case threatened the cohesion between the workers. One day, tensions rose high and resulted in a clash in the evening hours. The local police arrested six community members and jailed them until they calmed down. The workers group split up into two factions again and our research team halted the work for 22 days until the cousins resolved their problems. Eventually, a traditional Bedouin shaykh from the outside mediated and the conflict was solved by the usual payments to each other. The work could continue but the spirit was lost. The final day was on 16 September 2000 and was concluded with the killing of three sheep. The technical result of the renovation was positive and the team measured a 30% increase in water flow in the winter directly after the cleaning. Perhaps more important, despite the social difficulties, 16 young villagers have learned how to maintain their community's qanat.

A second renovation took place in Dmeir in 2001. The users community was well organised into a traditional system of "water committees" and "water guards" supervised by the farmers' cooperative. They were also willing to pay part of the renovation costs themselves from their credit system. Also involved were the General Directorate of Antiquities and the Regional Directorate of Irrigation of the Awaj/Barada Basin, active in qanat renovation in the Damascus Province. In this way, both the formal and the informal institutions were participating. The research team called for a meeting to discuss the renovation process. The attendants were the qanat committee members, notable persons from the community, and representatives from both the General Directorate of Antiquities and the Regional Directorate of Irrigation of the Awaj/Barada Basin. Based on priority activities, the costs and the participation of each party, a written contract was prepared to define each party's duties. A contract was developed and signed by each party. The period of the renovation was from November 2001 until February 2002. The actual renovation work was carried out by a group of contracted labourers, supervised by the head of the qanat committee. The damaged and eroded parts of the constructed walls were restored: almost 150 m^2 of the qanat walls was rebuilt. The qanat wall is 270 m long, and was built with stones 20-30 cm wide. The whole Qanat wall and a part of the ceiling were plastered, and damaged parts restored. Protective wall and covers were built for the cleaned airshafts and the qanat path was cleaned. The outlet was protected.

A third renovation effort was carried out in Qara between 2003 and 2004. One of the qanats in Qara, Ain el Taibeh, has provided the monastery of Deir Mar Yaqoub with water since its establishment during the Byzantine era. But the qanat ceased to flow in January 2002. The monastic community had requested our research team to compile scientific advice for them based on the survey work done in 2001 and 2002. This advice was duly developed in September 2002 concluding with social, institutional and technical recommendations for the qanats. The government support was reasonable: farmers were required to be involved at an equal level in the renovation efforts. The presence of the renovated monastery, its frescoes and the importance of the site for international heritage justified the assistance to maintain and conserve this valuable system as a human ecosystem. Having secured the outside funding from the Swiss, German and Dutch Embassies, the monastic community began preparing the renovation efforts at the beginning of September 2003. The work was carried out by the qanat experts and continued for ten days. The group of qanat experts consisted of 5 specialist workers from Ma'aloula and 3 builders from Nebk. All workers had experience with qanat renovation. The group from Nebk was specialised in the traditional building of tunnels using slabs of stones whilst the group from Ma'aloula cleaned the tunnel and reinforced the airshafts. A daily supervisor was appointed from the Ma'aloula group. A representative from the Irrigation Directorate of Awaj/Barada Basin regularly visited the site to inspect the work. The mother of the Monastery of Deir Mar Yaqub took care of the overall project coordination. On 11 April 2004, the renovation work was finished and the monastic community measured an increase of water supply.

Voices of Qanat Users

Renovating qanats is not only technically difficult, but it also means challenging the modern lifestyles and mindsets of (young) people by introducing them to a type of “green living”. A collection of video interviews forms the basis of an analysis of perspectives of qanat users. These interviews shed some light on why renovation efforts were and were not successful. The most important question during the interviews was why people are abandoning qanats and not keeping up the maintenance like before. Some quotes of qanat users:

“The young people want more income and they do not get it from the land we have now. It is more profitable to go and earn your money with something other than farming the bustan.”

“Those who are not interested in agriculture, they do not care and they went to get jobs in the government and are the ones who abandon the qanats. In the last 50 years because the income from other sources is better, they left for the other jobs.”

“I have already 100 descendants joined in the “house of Abu Zaal”. I can call myself a great-grandfather and they all want bread,” he says “and because of the economical reasons, the young people abandon the qanat.”

“Dmeir used to be a small village built around the temple with a wall and 7 doors that would close at night. In 1937 two major floods destroyed a lot of houses and people were forced to move or fall back on government support until 1945. They built houses outside of the city walls. There were also Dmeiris who lived abroad in the States and Europe and they donated money to build houses further. Then the city developed, we received domestic water supply, electricity, roads and telephone. Also the way people made a living changed. The French came and established an army base which gave a lot of jobs for us. People opened shops because this place is good for a stop-over between Damascus and Palmyra. So people moved away from agriculture and also demanded more money and could spend more money because of their salaries. Because of the little ownership, they keep it just for exercise or hobby farming, they rent it out or sell their rights when they need money.”

There is general consensus that due to the increased population, socio-economic changes and modernisation, the profit from qanats is not sufficient anymore for user households to maintain their lifestyle. Therefore, qanat renovation should provide a worthwhile profit, which can be sought in the form of value-added crops and ecotourism/cultural heritage value.

Another important aspect for successful qanat renovation is strong local leadership (Wessels, 2003). In Arak, the willingness of qanat users to invest in renovation was very low due to internal disputes that were not resolved by the community leader. Therefore, renovation did not take place. Even with outside help and funding, a participatory renovation effort would probably have increased tensions between the villagers. This is exactly what we observed during the pilot renovation in Shallalah Saghirah; the old social hierarchical system had collapsed. This was further exacerbated by population growth, internal competition, erosion of leadership and out-migration. A user illustrated this by his remark “Our five forefathers were like one hand, their system took care of the qanat and prevented children and sheep damaging the trees in the garden and they grew all kinds of vegetables and even cotton....but those after them did not keep these rules, the system did not last!”. The introduction of participatory approaches during the pilot renovation paradoxically caused users’ increased suspicion and contempt towards each other. In hindsight, not all users respected the leadership of the democratically elected village supervisor and an old revenge flared up in the process. The main problem at the pilot site was the lack of local leadership to manage the conflicts between these users.

The renovation efforts in both Dmeir and Qara were successful and we found that an important reason for this success was the presence of strong and respected leadership and a long tradition of rules, regulations and agreement between users. There are some consistent findings that emerged from empirical research in collective action, one of them is that when the users of common-pool resources organize themselves to devise and enforce some of their own basic rules, they tend to manage local resources more sustainably than when rules are externally imposed on them (Ostrom, 2000; Balland and Platteau, 1999; Wade, 1998). As a result, both in Qara and Dmeir there was no open dispute about decisions and the users community invested a great deal in the costs of repair and maintenance. Any disputes were dealt with inside the traditional conflict management system guided by a shaykh or mukhtar (village leader). Furthermore, professional expert contractors rather than users themselves carried out the dangerous renovation work.

Policy Options

Desertification and drought are the main, inter-linked climatic challenges in the Middle East, and dwindling water resources will put continuing pressure on society and water users. These developments call for sustainable techniques of using water. Often the solution is sought in modern technology, such as desalinization of seawater, but traditional techniques of sustainable water use can be found on the ground. In an ideal future, a new sustainable way of living will halt the pressure that human population puts on natural resources. The re-use of qanats for sustainable water management could contribute to such a lifestyle. Middle Eastern countries that have qanats should carefully consider whether government subsidies should be directed towards renovation of these systems.

As we have observed, successful renovation of qanats in Syria is technically possible; however, a thorough social and hydrological assessment is required in advance. We developed some ideas that can be used to decide whether it is feasible to renovate.

The following are the main points to consider for renovation:

- willingness of community to invest in future cleaning and renovation;
- existing technical knowledge of local people;
- social cohesion of the users' community;
- presence of a conflict management system;
- avoidance of excessive pumping around qanat source; and
- a guarantee of safety for qanat cleaners.

Participatory approaches are preferred and the ultimate responsibility and monitoring of the renovation should be with the farmers' cooperative. However, care should be taken with introducing the notion of "democracy" into this scenario. If familiarity with democratic principles is low at the community level, participatory approaches can potentially lead to conflict. The pilot renovation proved that the introduction of participatory approaches increased tensions between users, and the presence of a strong local leader would have been valuable. We hope with these efforts to preserve the traditional knowledge on qanats that still barely exists in Syria, and by starting with the community needs and priorities to revive sustainable qanat use for the future.

Acknowledgements

The development research was conducted by the following research team: Joshka Wessels (Anthropologist/project manager), Robert Hoogeveen (Hydrogeologist), George Arab (Research Assistant), Naser Hillali (Research Assistant), Robert Barneveld (Student Assistant), Aden Aw-Hassan (Programme Supervisor). Fieldwork of the project has been executed by the International Center for Agricultural Research in Dry Areas (ICARDA) funded by the Netherlands Development Assistance (NEDA), the Swiss Development Cooperation (SDC) and the Embassies of the Netherlands, Germany and Switzerland in the Syrian Arab Republic.

This text is published under the auspices of the United Nations University (UNU), Tokyo, Japan with special recognition to Dr. Zafar Adeel and Professor Iwao Kobori.

References

Baland and Platteau (1999) "The ambiguous impact of inequality on local resource management" World Development 27: 773-788.

Beaumont, P., M. Bonine and K. Mc Lachlan (eds.) (1989) Qanat, Kariz and Khattara. Traditional water systems in the Middle East and North Africa, USA.

Goblot, H. (1979) Les Qanats, une technique d'acquisition de L'Eau. Ecole des hautes etudes en sciences sociales, Centre de recherches historiques, France.

Lightfoot, D. (1996) "Syrian qanat Romani: history, ecology, abandonment" Journal of Arid Environments, USA.

Ostrom, E. (2000) "Collective Action and the Evolution of Social Norms" Journal of Economic Perspectives 14(3): 137-158.

Wade, R. (1988) Village republics, economic conditions for collective action in South India, IDS, Cambridge, UK.

Wessels, J. (2003a) Qanats in Syria, ease the water shortage, Waterlines 22(2): 8-10, ITDG Publishing, UK

Wessels, J.I. (2003b) "Community action for evaluating the use of common water resources in Syria in face of Poverty, Capabilities, mobilization and institutional transformation" In: Proceedings of the International CERES Summerschool 2003, KIT, Amsterdam, Netherlands: 358-376.

Traditional Water Harvesting on the Mountain Terraces of Yemen

Najib M.A. Al-Ghulaibi

Introduction

This chapter presents a study that was sponsored by the United Nations University and carried out by the author over a two-year period from May 2003 to April 2005. It formed part of an initiative to maximize water delivery to farmed terraces in the northern mountains of Yemen, as well as to improve storage conditions for provision of water for human use during the dry seasons of the year. The proposed interventions were envisaged as a way of improving the economic value of the farmed terraces and sustaining cultivation. The overall goal was to halt terrace degradation and stop their abandonment as part of a move to limit migration from rural areas to the cities. Objectives of the study included development of ways to optimize use of seasonal precipitation and to increase the spring base-flow for irrigating the farmed terraces during the dry seasons.

Mountain Terraces and Rainwater Harvesting in Yemen: A Historical Context

In prehistoric times, Arabia enjoyed more rainfall than today. The situation changed around 4000 BC when the so-called mid-Holocene moist phase came to an end and the climate started to become much dryer (McClure, 1988). The diminished spring and summer rains brought adequate precipitation to sustain modest covers of vegetation, but the crops no longer grew as abundantly as before. The early settlers of the Yemeni mountainsides were thus forced to use every possible patch of soil for cultivation. In addition, they faced a challenge when the slopes started to become denuded, and high rainfall events were accompanied by severe soil erosion. Terracing the steep mountain slopes was an answer, and through an enormous labour input the farmers created millions of terraced fields in the Yemeni highlands (Vogel, 1987).

Where the rains were not sufficient to grow a crop to maturity, the farmers began simple, but very effective methods of harvesting rainwater from adjacent rocky slopes serving as catchment areas. These types of simple devices are still employed today. Man-made diversions are created by heaping up gravel and stones. As soon as it rains, the run-off is funnelled by the artificial berms into broader channels which direct the water from the bare hillsides onto the terraced fields. The system is called sawaji irrigation, using the local Yemeni Arabic term (Vogel, 1987). A quantitative analysis of rainwater harvesting for terraced agriculture in today's Yemen is given by Eger (1984) for the Amran region in the central highlands of Yemen, and by Rappold et al. (2003) who provide data for the more southerly region of Taizz.

Terraces function as both soil and water conservation structures on sloping land. The process of soil erosion down-slope is greatly slowed due to retention of the run-off on the terraces. It has been documented archaeologically that terrace construction in Yemen dates back to at least the 3rd millennium BC (Wilkinson, 1999). Large parts of this terraced terrain have been cultivated continuously since that time.

Figure 1. Traditional water harvesting in the mountain terraces (Al-Qimmah watershed during rainfall. *Source:* Al-Ghulaibi, 2004)

Until 50 years ago, people in the mountainous areas of Yemen were highly dependent upon rain-fed agriculture on the picturesque terraces that give Yemen its distinctive landscape character. Traditionally, water harvesting was an appropriate and brilliant solution for sustainable and secure food production. But newer approaches need to be found today to correct for the imbalances introduced through more recent developments.

Study Area and Natural Resources

The al-Qimmah watershed is located in the northern highlands of Yemen, in Hajjah Governorate (see map, Figure 2). The main road from Amran to Hajjah Governorate crosses the upper part of the watershed (see map, Figure 3). The study area covers approximately 700 ha, comprising the watersheds of Wadi Abr Jaher and Wadi Mqaled. Steep, terraced mountain slopes, a rocky escarpment and green valleys characterize the watershed. The elevation ranges between 1600 and 2700 m above sea level. Erosion of volcanic lavas and pyroclastics has furnished rich soils (Vogel, 1987).

The annual rainfall is between 250 and 450 mm, with the precipitation occurring mainly in two monsoon-influenced rainy seasons: spring (March to May) with medium rainfall, and summer (July to September) which accounts for 50 to 60% of the annual precipitation. Overall, the rainy season of the year is short, falling within at most 4 to 6 months per year, and the dry season lasts for 6 to 8 months. During the spring rainy season, though the precipitation is often infrequent, the rain falls normally with great intensity which results in high surface run-off of the water into the bed of the wadi flood courses. This run-off may be collected in storage facilities. Yet, during the dry season when the clouds dissipate, the persistent sunshine causes high evaporation of water stored in uncovered reservoirs.

For Hajjah Governorate, the average PET (potential evapo-transpiration) is 2.7 to 3.3 mm per day during the dry, cold period and 4.5 to 4.8 mm per day during the months April to June. The average total amount of ET (evapo-transpiration) per year for Hajjah is about 1425 mm.

Problem Definition

For the agricultural cycle, the climatic conditions pose two challenges: the length of the dry season and the great annual variability in the precipitation pattern, which results in major changes of the agricultural production from one year to another. Naturally, a shortage of precipitation leads to a significant decrease in yield. The extended periods without any precipitation at all have a serious deleterious effect on plant growth. This can result in severe physiological degradation of the plant, especially in the root zone. Low ground moisture retards root growth and causes leaves to fall prematurely.

When the rainfall starts again after a long period of drought, plant recovery is slow. Therefore the crops need to be carried through the long dry season by the provision of supplementary irrigation using water stored in reservoirs during the previous rainy season. Other possibilities are the application of traditional water harvesting techniques, or re-direction of water from springs to the fields. Supplementary irrigation during the dry season can increase the crop yield three times, as shown by field trials.

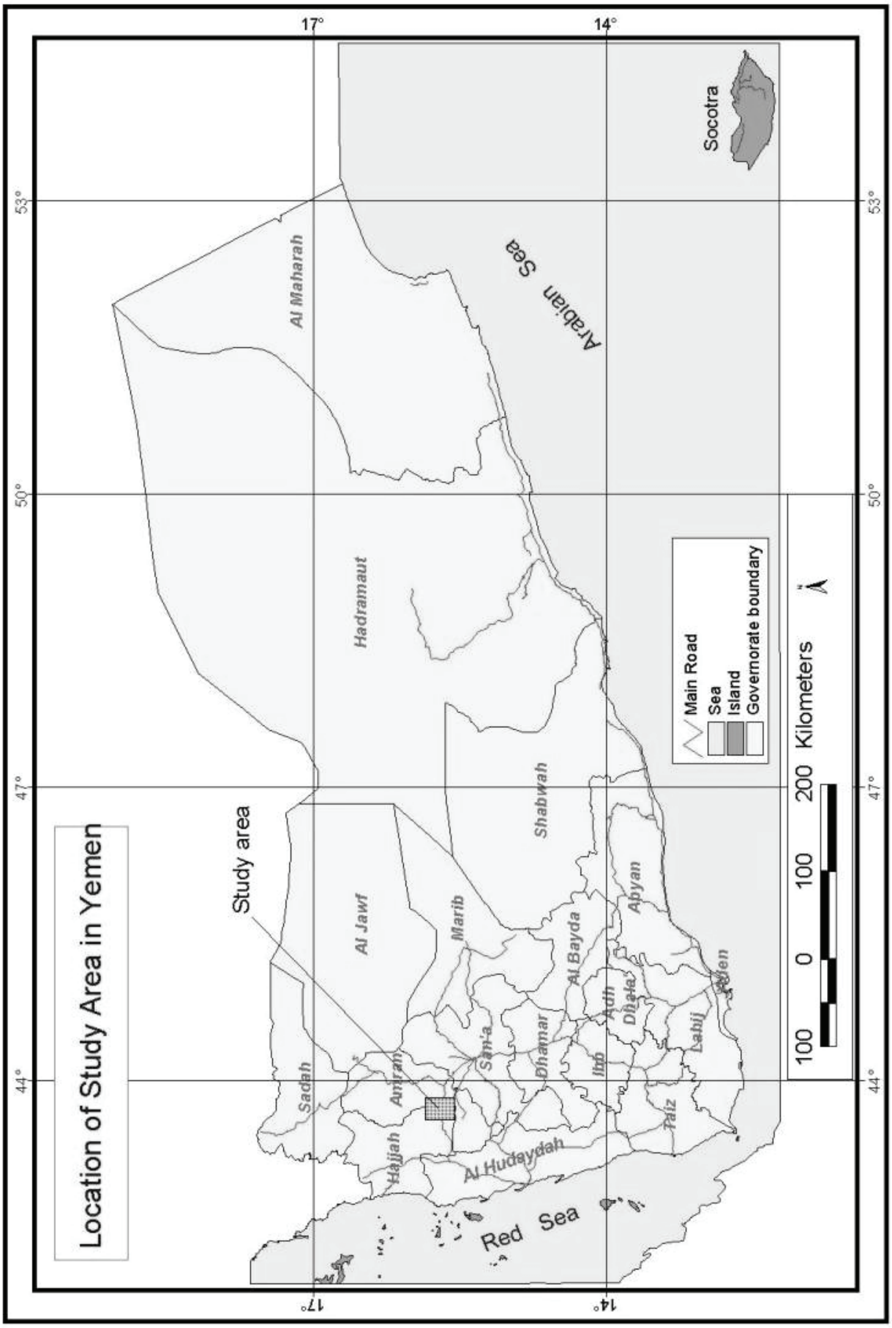


Figure 2. A map of Yemen showing the location of the study site.

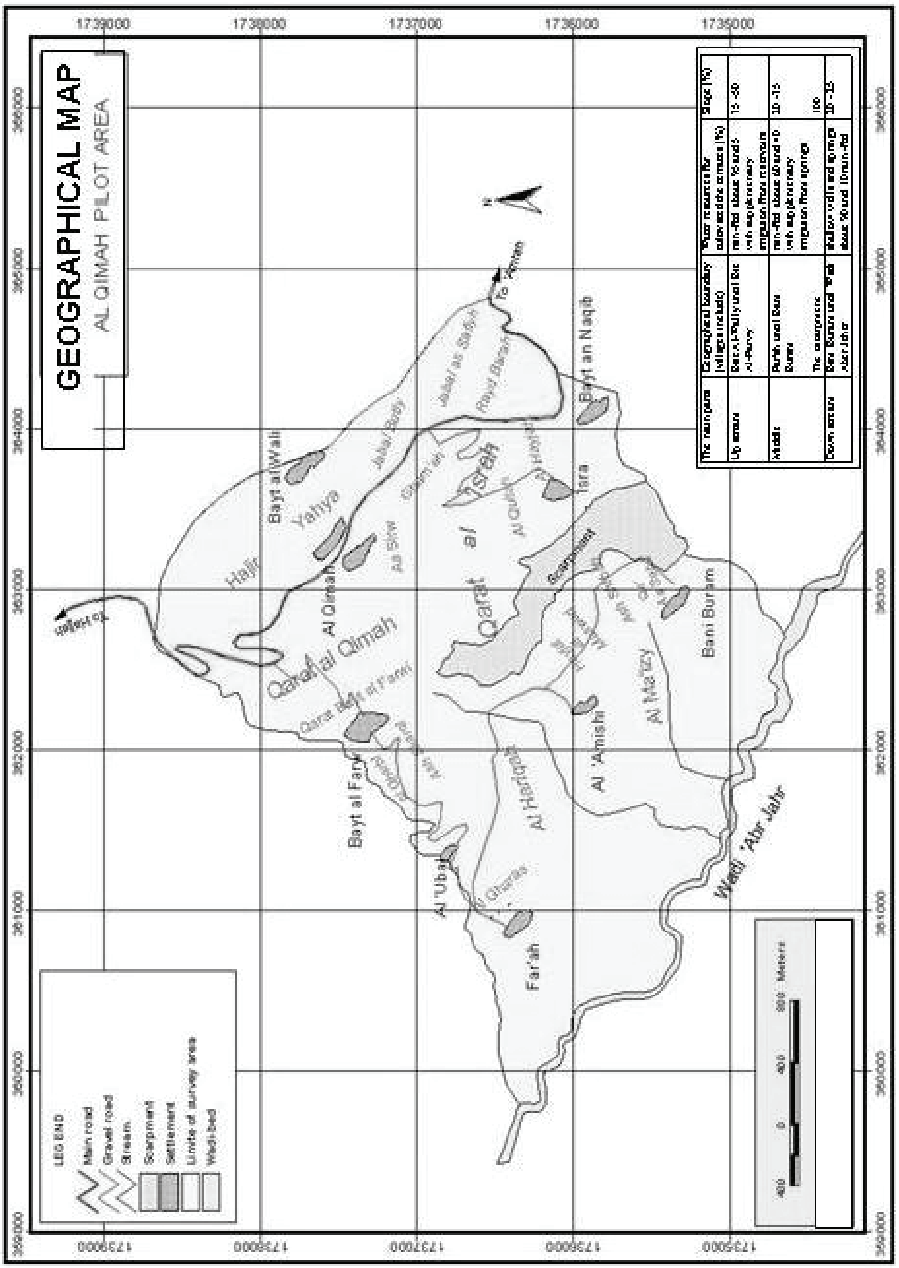


Figure 3. Geographical map of the study site.

In addition to the need for supplementing field irrigation, there is the problem of domestic water shortfalls during the dry season. Beginning in November, the water drawn from springs and stored in reservoirs starts to diminish. People are obliged to bring water from valley bottoms - using the base flow in the wadis - to the villages high up in the mountains, which can be done in this day and age through trucks. The cost of one litre of water delivered by this means is about 10 YR (Yemeni Rials) for a distance of approximately 1 km from the source of water to the village (100 YR = $US 0.55, according to the exchange rate for 2005).

The average consumption of drinking water is 3 to 4 litres per capita per day, equalling 100 litres per month per person. If the family consists of 10 persons, the monthly consumption will be 1,000 litres. Therefore the cost of water for this family would amount to 10,000 YR (= $55). Given an average monthly income of the farmer of 10,000 to 15,000 YR, there is clearly a financial problem here, which contributes to abandonment of the villages by farmers seeking work opportunities in cities. The alternative is to rely exclusively on women and children to fetch water from the base flow in the wadis or from springs, which may be considerable distances away, and to deliver the water to the villages on the high mountainsides. Women and children, together with draft animals, have to travel up to 2 to 3 kilometres on foot per day over arduous terrain for this purpose, carrying heavy weights. The expenditure of human energy and time is enormous.

The problems described above are intensified by the following considerations in the study area, which also affect Yemen in general, and have particularly damaging effects on the traditional system of terraced agriculture and rainwater harvesting:

- The patterns of rainfall have changed; this has had deleterious consequences for rain-fed crop production.
- The population has increased rapidly, and the need of food and water increased accordingly. Population growth at 3% per year means that the population doubles over a 20-year period.
- Groundwater levels have dropped because of over-consumption of water. This has enormous implications for the sustainability of agriculture.
- Abandonment of terraces due to urban migration and the collapse of terraces due to road construction are causing uncontrolled run-off that is damaging the downstream terraces (for details see Vogel, 1987).

Traditional Rainwater Harvesting on the Mountain Terraces: The Annual Cycle

From observations in the study area (both upstream and in the middle of the watershed), and from field interviews, we can trace the water harvesting practices over the course of an entire calendar year.

A. During the dry winter season (October to February) the farmers perform the following activities:

1. They repair the damaged terrace walls. Sometimes the farmers collaborate to rebuild collapsed walls, in which case the owner of the terrace normally provides the others with food during the course of the work. In instances where the farmer opts to pay for the labour, the cost for rebuilding a length of walling 10 m long and 2 m high amounts to about 9,000 YR (= $50). The work starts with the emplacement of the large stones first, and then the small rocks and soil packing are added.
2. Berms need to be erected around the edges of the terraces (about 0.5 m above the ground level of the terrace) to allow water to be trapped on the land. Each farmer does this on his own terraces.
3. The catchment area of each group of terraces (Yemeni dialect Arabic: *sebab*) needs to be cleared of loose stones in order to maximise run-off. These catchment areas have different parts, depending on the slope and surface configuration.
4. Maintenance work of the main delivery channel, which is normally 1 to 3 m wide and 1 to 1.5 m high, involves clearing it of rock and sediment accumulations, in order to facilitate delivery of run-off water to the terraces. The same applies to the branch channels and the main drainage channel (Yemeni dialect Arabic: *kuthwam*), some 0.5 m in width and 1 to 1.5 m high, which carries surplus water away from the terraces. It runs underground, with only the inlet and outlet visible. See Vogel (1987) for a similar description of an underground drainage system.
5. The terraces are ploughed, using draft animals. This is done three times. The first ploughing starts at the end of December, for the removal of grass and other weeds. The second ploughing happens after the first rain, to close the main soil pores and reduce evaporation. This is required to conserve as much moisture in the soil as possible. At the time of the second ploughing, the farmers also spread manure (from cows and sheep) onto the soil. The third ploughing, at the beginning of the spring season in March, is for sowing (Yemeni dialect Arabic: *sawab*), generally sorghum. In this last tillage, the farmers make furrows at right angles to the hillside gradient, in order to catch as much run-off as possible for the crop. The farmers plough and sow in one go, using a sowing funnel attached to the plough.

B. During the spring season (March to May), which is the first rainy season, the farmers perform the following activities:

1. They continue to repair and maintain the branch channels in order to maximize the run-off water directed to the terraces. As well, the so-called *mshanat*, Yemeni Arabic term for provisions made to catch small rocks and sediments before the run-off enters the terraces, are cleared.
2. If the run-off is low during the spring season, the farmers cultivate the fields with a slight slope running normally 0.5 to 1% back towards the mountainside. This reduces the loss of water that would otherwise flow over the terrace walls.
3. As soon as the rain starts, the farmer monitors his terraces. Some farmers will direct additional run-off water onto a terrace, while others may close their branch channel. This depends on the amount of the rainfall. In order to be able to drain surplus water from the upper terraces to the lower ones, in each terrace wall there is an outlet (0.3 m x 0.25 m) in the middle or at the end of the terrace wall (Yemeni dialect Arabic: *mansher*). This permanent stone emplacement allows excess water to pass onto the field below and plays a primary role in terms of soil erosion control.

C. During the summer season (July to September), which includes the main rainy season, farmers perform the following activities:

1. They monitor the terraces closely, because of the danger of flooding, following a heavy rainstorm. On these occasions the farmers may choose to breach the sides of the branch channels to prevent collapse of the saturated terrace walls.
2. Collaborative efforts are carried out to protect the crops on the terraces by diverting the main channel (Yemeni dialect Arabic: *sharm*) during time of excessive run-off.
3. One and a half months after sowing, the terraces are weeded to conserve soil moisture. In addition, the soil around the sorghum plants is hoed to reduce soil porosity and thereby deter evaporation.
4. After two months, the sorghum plants are stripped of about half of their leaves (Yemeni dialect Arabic: *kharf*), and the plants are thinned by hand to leave about 60,000 plants per hectare (see Berry, 1984, for details). These activities reduce plant transpiration and thereby help conserve soil moisture as much as possible, and at the same time they provide essential fresh fodder for animals.

Traditional Law of Water Rights

The traditional law of water rights in the study area varies from district to district. In general, there is an agreement between the farmers in each district, which is monitored by an elected local farmer; he has expert knowledge of the land and is familiar with the land-owners (Yemeni dialect Arabic: *al-muqaddim*).

From our interviews with the farmers, it became clear that the run-off water harvesting rights can be divided into two main components:

1. In the case of a farmer owning the run-off catchment area for his terraces, he may choose either to utilize the run-off on his land or to divert it to the terraces lower down. The farmer lower down does not have any prior legal right to the run-off water, and the farmer farther up may prevent him from receiving it.

2. In the case where more than one farmer shares ownership of the catchment, this area is divided between the individual farmers based on the size of the land owned. Each farmer's section of land has its own apportioned catchment, and no one is entitled to divert run-off water from one section to the other without permission.

When sufficient run-off occurs, farmers irrigate their terraces and direct the extra water from the upper terraces to the lower ones, until the water eventually reaches the wadi bed. The main channels are repaired and maintained through cooperation between all of the farmers. There is no standard legal provision that allows for run-off to be diverted across land owned by another farmer, unless there is a signed agreement in place.

Reservoirs for Run-off Water Storage

Storage reservoirs or cisterns (Yemeni dialect Arabic: *majil*, pl. *mawajil*) are common in villages high up in the mountains to collect run-off water. The following is an inventory of these cisterns documented in the study area (see map, Figure 3).

1. Bayt al-Wali village

This village lies at an elevation of 2,688 m above sea level. There are three reservoirs which were built between 1966 and 1967 from fieldstones, and their floors and walls are coated with a lining of waterproof lime plaster. In 2002 the cisterns were renovated using stones and cement. The catchment area from which the run-off is funnelled into the reservoirs is in the Safeah mountains and measures about 3.4 hectares, with a gradient of about 10%. Before the run-off enters the respective reservoir, there is a basin to allow small rocks and sediment to settle. In case of a heavy rain, the cisterns may overflow.

The holding capacity and dimensions of these reservoirs are as follows:

a. 207 m^3 (4.4 m × 15.7 m × 3 m)
b. 304 m^3 (13 m × 13 m × 1.8 m)

c. 346 m^3 (12 m × 12 m × 2.4 m)

The total volume of these three reservoirs is 857 m^3. The water is used for domestic purposes, as is an older cistern built 70 years ago with a capacity of 98 m^3 (5.6 m × 4.6 m × 3.8 m).

2. Kuhlan-Afar village
The largest reservoir in the study area is of unspecified age and there is no living memory of its construction. It is almost circular, with plaster coating on its sides and bottom to prevent seepage. A circular depression in the middle serves as a sediment trap. Run-off water is led into this reservoir through channels built with fieldstones and plaster lining. Along the sides of these channels are perforations to encourage silt deposition. A second reservoir of smaller dimensions is found next to the large one. The total volume of both reservoirs is about 4,000 m^3, and the water stored in them is normally used for domestic purposes. When the first reservoir has filled up, water from it can be diverted to the second one, and in case of there still being excess water, this surplus can be directed to the terraces.

3. Al-Qimmah village
A new reservoir was built in March 2004 by farmers with funding from UNU and in cooperation with the farmers. It is located in Ubar Hamzah close to the main road coming from the west. The capacity of this reservoir is 63 m^3 (5 m × 5 m × 2.5 m), and the total cost for building it was 350,000 YR (about $2,000). The water is used for two purposes – namely as domestic water and as supplementary irrigation for the terraces during the dry period. The objective of the project was as an experiment to see how many square meters could be irrigated from this reservoir. It was found that about 200 m^2 (approximately two medium-sized terraces) can be irrigated from one filling. Under the assumption that the reservoir is filled twice a year, the water would also be sufficient to irrigate a greenhouse area of 500 m^2, from sowing to harvest. Farmers could, for instance, grow cash-crops such as cucumbers and tomatoes under such controlled conditions which would mean an increase in efficiency of water use and at the same time an income increase.

4. Bait al-Farawy village
There is one large reservoir (Yemeni dialect Arabic: sud, which also has the meaning of “dam”), which was constructed of fieldstones and cement in 2002. The holding capacity of this reservoir is 1196 m^3 (51 m × 5.1 m × 4.6 m). The water is used for domestic purposes and for providing water to animals. Before the water enters the main reservoir, there are two small basins to allow sediments and small rocks to settle. Their dimensions are 5.1 m × 4.7 m × 1.3 m, and 5.1 m × 4.8 m × 3 m respectively. They are built at the end of the main channel that directs the run-off to the reservoir.

5. Al-Obal village

There are five reservoirs, three of which are used for both domestic purposes and supplementary terrace irrigation. One is exclusively for irrigation, and one for domestic purposes only.

a. A small reservoir (Yemeni dialect Arabic: *birka*) is located to the north-east of the village. The run-off water for this reservoir comes from the top of the mountain. The capacity of this reservoir is 81 m^3 (9 m × 4 m × 2.3 m). The water is used for domestic purposes and for irrigation.
b. A second small reservoir can be found near the school of the village. The run-off water is derived from the immediate area around the reservoir. The capacity is 166 m^3 (10.8 m × 4.4 m × 3.5 m). The water serves domestic purposes as well as irrigation of crops.
c. A third small reservoir is to the south of the village, and – as with the first one – the catchment area extends to the top of the mountain. The capacity is 33 m^3 (3.2 m × 4 m × 2.6 m). The water is used for domestic purposes and irrigation.
d. The fourth birka to the east of the village also receives its water from run-off from the top of the mountain. The capacity is 75 m^3 (5 m × 5 m × 3 m), and the water is used exclusively for irrigation. The reservoir was constructed by a local farmer, and he reported that he spent approximately 350,000 YR (about $2,000) on it.
e. Run-off from the mountain also fills a large reservoir (Yemeni dialect Arabic: *sud*) in the middle of the village. Its capacity is 10,000 m^3 (50 m × 20 m × 10 m). The water is used for domestic purposes only.

Assessment of the Reservoir Capacities

From the above data for the reservoirs located in the watershed study area, we can summarize the figures in the following way:

- The total storage volume of water is 16,571 m^3.
- The total population of the villages is 3,621 inhabitants.
- The average water consumption for drinking is 3 to 4 litres per capita per day, which amounts to approximately 100 litres per month. The total water demand for drinking purposes for the entire population is therefore 100 × 3621 = 362,100 litres per month, i.e. 362 m^3.
- The water demand for domestic use is 20 to 30 litres per capita per day, equalling 600 to 900 litres per month. For the entire area, the water demand for domestic use therefore amounts to 750 × 3,621 = 2,715,750 litres per month, i.e. 2,716 m^3.
- The watering needs for livestock is 10 to 15 litres per animal per day, equalling 300 to 450 litres per month. The total number of livestock in the study area is 767 (goats, sheep, cattle and donkeys), and the water demand of the animals is thus 375 × 767 = 287,625 litres per month, i.e. 288 m^3.

This results in a total water demand for one month of 3,366 m^3, i.e. 40,392 m^3 per year. Since the reservoir storage capacity is 16,571 m^3, the reservoirs can cover the needs for only 5 months of the year. The shortfall of water for domestic use and drinking purposes is therefore 23,821 m^3 per year, aside from the need for water for supplementary irrigation.

The numbers of reservoirs needed to cover the shortfall of water for domestic use, with an average reservoir capacity of 500 m^3, is 47 reservoirs. Given an average cost for each reservoir of approximately 2,000,000 YR (= $11,000), the total cost for providing these reservoirs would be about 94,000,000 YR (= $517,000).

Spring Flow Resource Management in the Watershed

There are a number of situations where channels drawn from base spring flow (Yemeni dialect Arabic: *ghayl*) provide an enormous boon for the sustenance of the fields. While the discharge rate of these springs is too low to have the water flow directly into channels, it is sufficient to fill a reservoir and then unplug it for irrigation. The springs documented in the study area are as follows:

1. Bani Boram

The water source is from Ghayl Arshan in the district of Jabal al-Taweel (Figure 4). The capacity of the reservoir fed by the spring is 180 m^3 (12 m × 5 m × 3 m). The discharge rate is at 14.9 m^3 per hour, reflecting a flow of 248 litres per minute (approximately 4 litres per second). This is sufficient to allow the reservoir to be filled and used (emptied) twice a day, once in the morning and once at night, so that the total volume of water from this ghayl is about 360 m^3 per day. The number of farmers served by Ghayl Arshan is 355. The area irrigated in this way amounts to about 1,500 labn (local land measure, 1 *libna* = 64 m^2, pl. *labn*), which equals 9.6 hectares.

Figure 4. Ghyle Arshan (spring) (photo courtesy of Dr. A. Bruggeman).

The main irrigated crop is coffee plants, in addition to vegetables (onions, salad greens) and qat. The rotation cycle is 18 days, which means that each farmer has the right to receive water from the ghayl once every 18 days. Therefore, 20 farmers per day can irrigate using water from the ghayl. The rotation system is monitored by a muqaddim who ensures that the different users receive equitable water shares.

2. Ghayl Ubar Joher:
The capacity of the two reservoirs served by this ghayl has a total of 105 m^3 (9 m × 5 m × 1.5 m = 67.5 m^3, and 5 m × 5 m × 1.5 m = 37.5 m^3 respectively). The reservoirs can be filled (and emptied) 4 times per day (Figure 5). Therefore the total daily volume of water from this ghayl is about 420 m^3. The discharge rate is 17.5 m^3 per hour, which is 292 litres per minute (approximately 5 litres per second). The rotation cycle for the farmers is 21 days. The irrigated area is about 1200 labn, which amounts to a total irrigated area of 7.7 hectares. The irrigated crops are coffee plants and banana trees. As in Bani Boram, it is the muqaddim’s responsibility to monitor the rotation system.

Figure 5. Ghyle Oper Joher (photo courtesy of Dr. A. Bruggeman).

3. Ghayl Nad
The capacity of the storage reservoir is 70.7 m^3 (9.3 m × 7.6 m × 1 m). The reservoir is filled twice a day, so the total amount of water is about 141 m^3 per day. The potential discharge rate is at 5.8 m^3 per hour, meaning 97 litres per minute (approximately 1.6 litres per second). Coffee plants, bananas and sorghum are the main irrigated crops. The water rotation between the farmers is on an 18-day cycle. The irrigated area is about 2,500 labn, so the sum total amounts to some 16 hectares of irrigated farmland.

Conclusions

A drier climate combined with population growth and a changing global economy has produced enormous pressures on the sustainability of terrace agriculture in the Yemeni highlands. Since the beginning of the Holocene, the environment in this area has been fragile. Human ingenuity devised ways to sustain settlement in these marginally arid regions, through construction of terraces and diverse water harvesting structures. Over time, these techniques have proven to be effective.

Neglect of these water harvesting systems, however, as a result of relatively poor economic return, threatens to destroy the entire ecosystem. Because of water scarcity, low income from terraces that depend purely on direct rainfall, and high labour intensity of the agricultural activities, there is an increasing tendency to abandon this way of life. The only way to halt the trend is to increase the income for the farmers and lessen the burden of work. The solution is to maximize the use of immediate run-off and to collect and store more of it before it is lost to the wadi flood courses. The test cases presented in this study may serve as an example of how to preserve traditional mountain terrace agriculture in all of Yemen.

References

Al-Ghulaibi, N.M.A. (2004) Traditional water harvesting on the mountain terraces of Yemen, Study Report submitted to United Nations University, Tokyo, Japan.

Berry, R.H. (1984) Preliminary Observation of Soil Moisture Conservation and Water Harvesting Practices in Dhamar Governorate. Agricultural Research and Extension Authority, Dhamar, Yemen.

Eger, H. (1984) "Rainwater Harvesting in the Yemeni Highlands: the effect of rainwater harvesting on soil moisture status and its implications for arable farming, a case study of the 'Amrān region" In: Kopp H. and G. Schweizer, (eds.) Entwicklungsprozesse in der Arabischen Republik Jemen, Wiesbaden, Jemen-Studien 1: 147-169.

McClure, H. A. (1988) "Late Quaternary Palaeogeography and Landscape Evolution of the Rub' Al Khali" In: Potts, D.T. (ed.) Araby the Blest. Studies in Arabian Archaeology, Copenhagen, Carsten Niebuhr Institute Publications 7: 9-13.

Rappold, G.D., P. Ergenzinger, H. Gerke, and F. Scholz (2003) "Hydrological nalysis of terraced catchments: a case study of the Taizz region, Yemen" In: al-Hakimi, A. and F. Pelat (eds.) Indigenous Knowledge and Sustainable Agriculture in Yemen. Sanaa: Les cahiers du Centre Français d'Archéologie et de Sciences de Sanaa 3: 71-78.

Vogel, H. (1987) "Terrace farming in Yemen", Journal of Soil and Water Conservation 42(1): 18-21.

Wilkinson, T. (1999) "Settlement, soil erosion and terraced agriculture in highland Yemen: a preliminary statement", Proceedings of the Seminar for Arabian Studies 29: 183-191.

Khattara and Water User Organizations in Morocco

Keiko Oshima

Introduction

In arid and semi-arid regions, located at the southern and eastern margins of the Atlas mountain range, in Morocco, people live within oases relying mainly on traditional water systems called *khattara* (qanat). The khattara system has been a common form of underground water utilization since its development several hundred years ago, especially in Tafilalet region where it extends to the southeastern part of Morocco (Oshima, 2001).

There are about 570 khattaras in this region; however, only around 250 are currently operational (ORMVA/TF, 1997). This reduction in numbers is caused mainly by drought and other multiple related factors. It has become difficult to maintain khattara because of the economic difficulties related to drought (Oshima, 2004). To improve the present situation, khattara water users started to establish associations, essentially non-governmental organizations (NGOs), for getting financial support for khattara rehabilitation work.

This chapter focuses on the role of these associations on khattara management. The data on traditional organization of khattara and associations were collected mostly through interviews conducted by the author.

A Brief Overview

The government of the Kingdom of Morocco advocates the importance of participation of inhabitants in developing national agriculture and rural development policy. In this policy, the importance of NGOs and local organizations is highlighted (Ministry of Agriculture, Rural Development and Sea Fisheries, 1999). It also refers to the necessity of reinforcing capability of these organizations to cooperate with other organizations including administrative organs (ibid.).

In line with this policy, the Regional Agency for Irrigation and Agricultural Development of Tafilalet (hereinafter referred to as “ORMVA/TF”, in French, Office Régional de Mise en Valeur Agricole du Tafilalet), was created by the government in 1966 and has been promoting the establishment of Associations. The ORMVA/TF has been trying to support traditional khattara water users organizations to transform to Associations since 2000 to cope with the high demand for financial assistance for khattara rehabilitation in the region (Oshima, op.cit).

In general, khattara systems fall under the supervision of the traditional khattara organization composed of water users. The management of water from khattara for irrigation is regulated by the customary law of distribution, known as water rights. The water cycle of khattara varies from 8 to 25 days, and is utilized by approximately 100-200 people. Each water user's organization divides water users into irrigation groups of specific length of water rights, and selects representatives (called *mzrag*, pl. *mzārīg*) from each group. One leader (*sheīkh*) of the khattara is also selected among water users (Figure 1). Hence, typical traditional khattara organizations have a leader representing a few hundred water users.

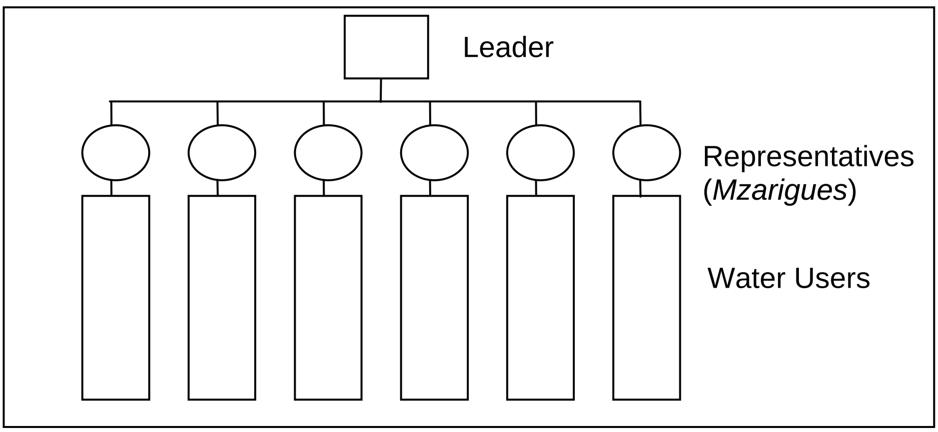


Figure 1. A schematic representation of the structure of a traditional khattara organization.

The traditional khattara organizations are managed by water users and carry out khattara maintenance and rehabilitation works by fairly distributing their workloads and financial burdens in proportion to the amount of water rights of each individual. The experience, knowledge and unity of water users accumulated through these activities provide a strong basis for continuation of maintenance and rehabilitation.

However, the traditional organizations do not have legal status or registration, and their operation does not fall under the local laws. Because of this reason, external organizations, including international development agencies and NGOs, are reluctant to extend their support to these traditional organizations. On the other hand, the Associations must be established in accordance with the Association Law enacted in 1958 and partially modified in 1973 and 2002

(Benyahya and Bouachik, 2003). Therefore, the establishment of associations which include khattara development in their activities has been gradually spreading among khattara villages.

Classification of Associations

Associations related to khattara management can be classified into two categories according to their field of interest: (a) associations whose activity specializes in khattara management; and (b) associations aiming at supporting all activities related to rural development, including khattara. The former is referred to as Khattara Associations, while the latter as Associations for Rural Development. Both types of associations are registered by the government through a prescribed procedure; there is no difference in the legal status between the two.

The three main objectives of Khattara Associations can be summarized as distinct stages:

1. To prepare khattara development projects, which require financial assistance from external organizations;
2. To demonstrate the importance of khattara systems in local development; and
3. To increase the income of people living in khattara villages.

So far, most of these associations have only focused on the first stage; they have not yet been able to expand the scope of their activity to the next stages.

Associations for Rural Development have been established by local people for sharing common interests, with similar three-stage actions. In Tafilalet region, 191 Associations were established. The primary of these associations focuses on rural development, social development, and cultural exchange in order to improve the standard of living of the population in rural areas (ORMVA/TF, 2003).

Case Study – The Jorf Area

The author selected the Jorf area (the region of Fezna-Jorf-A.S. Ghèris, at a distance of ca. 7 km from Erfoud in the north-west) in Tafilalet region, for carrying out the field survey in 2004 (Figure 2). In Jorf area, there are 59 khattaras, but only 19 (32%) are currently operational. The criteria for selecting this area as a case study were: 1) existance of numerous operational khattaras; 2) associations related to khattaras have already been established; and 3) the *status quo* and types of associations varies significantly in the area.

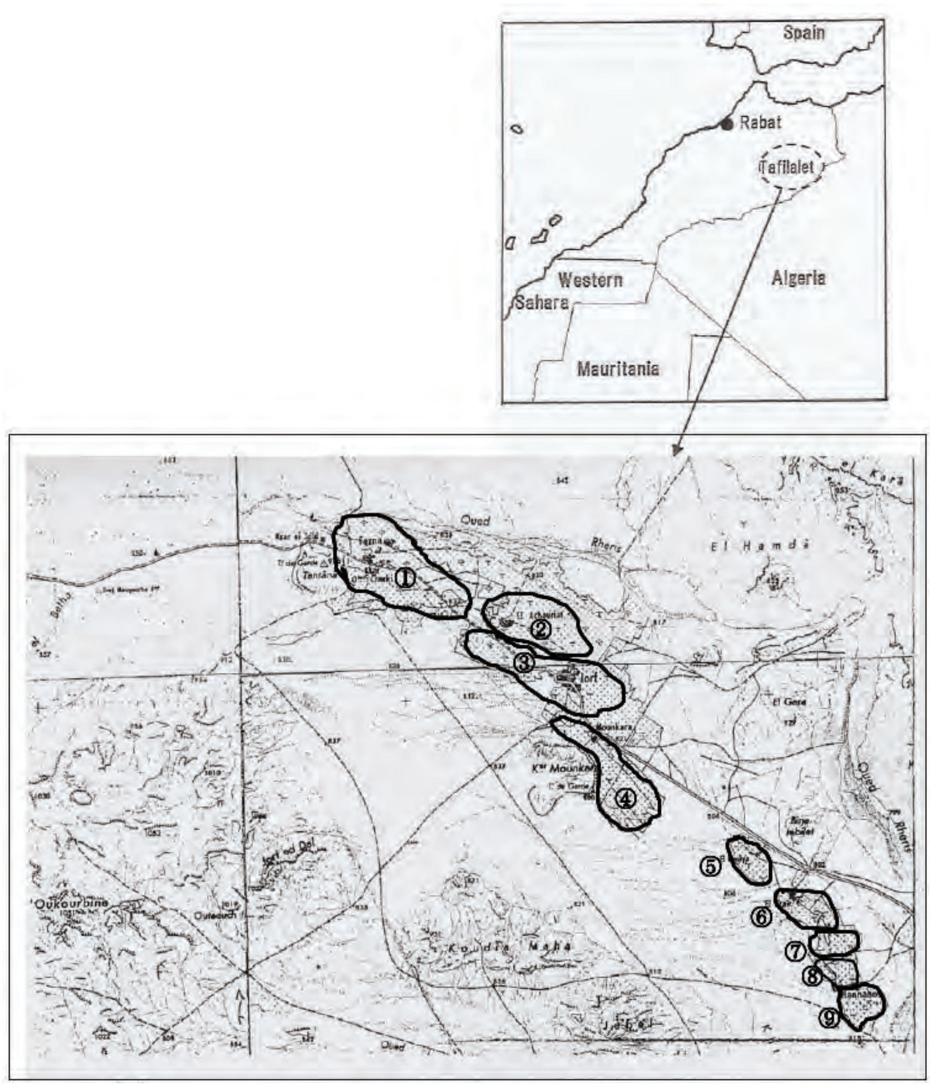


Figure 2. Map of Associations in the Jorf area.
Legend: ① Gfifat Khattaras Fezna; ② Achauria Khattaras; ③ Jnan Nbi Khattaras Jorf; ④ Mounkara Khattaras; ⑤ El Amal; ⑥ Al Kheir; ⑦ Lakhtitira Khattara Hannabou; ⑧ Ghriss Khattaras Hannabou; and ⑨ El Ouahda Khattara Qadimat Hannabou.

The ORMVA/TF has been trying to facilitate the provision of governmental support to khattara rehabilitation efforts, mainly by transforming traditional organizations into formal and legally registered associations. At first, they attempted to unite all the khattaras in this area into a single organization. But through discussion with the representatives of each traditional khattara organization, they agreed to create nine distinct Associations (please see Figure 2). This reflects the aspiration of the local people, who had strongly hoped to establish an association for each village, or even each khattara.

As a result of this effort, eight Associations were established in Jorf area during the year 2001, except for the El Amal Association which was already well-established a year earlier. Seven of these associations are classified as Khattara Associations, and two are Associations for Rural Development. The number of the khattaras that belongs to one Association varies from one to twenty four. We can also find associations whose active area covers more than one village (Table 1).

Table 1. Office members of the associations in Jorf area.

Association Name	Number of Office Members	Number of Khattara†	Status in the Traditional Khattara Organization		
			Sheikh	Mzrag	Water User
Gfifat Fezna	9	10(10)	1	-	8
Achauria	7	5(5)	2	1	4
Jnan Nbi	21	24(21)	10	10	1
Mounkara	13	4(0)	4	7	2
El Amal	13	4(2)	2	4	7
Al Kheir	9	2(0)	2	6	1
Lakhtitira	9	1(0)	1	4	4
Ghris Hannabou	9	8(2)	5	2	2
Al Ouahda	9	1(0)	1	4	4
Total	99	59(40)	28	38	33

†The number in parenthesis indicates the number of khattara without water at present.

Also a union, comprising presidents of all the nine associations in this area, was also established in order to develop common strategies to cope with the threats to khattaras in the area. One of the greatest threats is the expansion in the use of motor-pumps for irrigation in upstream or catchment areas, leading to the decline of groundwater tables. The union also facilitates exchange of information and knowledge acrss the khattaras.

The Status Quo of Associations

In Fezna, both associations of Gfifat and Achauria are not active. This is a result of depletion of the respective khattaras. All khattaras in this district have already dried up since the 1970s because of the lowering of the groundwater level due to widespread use of motor-pumps in the upstream area. Those responsible for establishing khattara associations in the Fezna district have faced general indifference from the users, who formerly relied on khattaras. Despite these hurdles, the associations were established at the insistence of ORMVA/TF. There is a local belief that the water availability in these khattaras may be restored in the future and the association might be useful.

In the two districts of Jorf and A.S. Ghèris, five Khattara Associations and two Associations for Rural Development were established. Some of the associations have already been successful in securing economic assistance from external organizations. It is interesting to note that receiving external aid seems to be a matter of chance rather than a reflection of the level of effort or activity by a particular association. When economic assistance is granted by an external organization, they often choose a khattara using their own criteria, thus bypassing the preferences of the respective association. This complicates the role of associations and local users tend to favor creation of associations for individual khattaras. The associations in these districts are striving to change this pattern.

For associations spanning more than one village, consensus building and cooperation work is quite challenging because each village has its own interests and priorities. People of each village or each khattara openly expressed their strong intention for establishing their own organization. This obviously points to a misunderstanding about the concept and role of these associations.

When compared to the Khattara Associations, the Associations for Rural Development are very active. They have greater experience in project implementation in partnership with external organizations. Their engagement is in the day-to-day activities of people.

In the case of the union, the members have been dissatisfied with the leadership and have expressed reservations about the utility of the union. While the union is dormant, members of the union are considering a change in the presidency as a way of reactiviating it.

Relations Between Associations and Traditional Khattara Organizations

In general, a traditional khattara organization comprises water users and manages all issues concerning khattara. Therefore, there is a tendency of people who have a high status in the traditional khattara organizations to also become office members of the respective associations (please see Table 1). In some cases (e.g., Lakhtitira Association and Al Ouahda Khattara Qadima association), all office members are representatives belonging to a traditional khattara organization. This type of association can be considered as a “reinforced” traditional organization by achieving a legal status.

When an association works on more than one khattara in a village (e.g., Mounkara Association, El Amal Association, Al Kheir Association and Ghris Hannabou Association), each khattara selects their own representative from either a traditional khattara organization or water users. This leads to a multiplicity of institutional arrangements.

Al Kheir Association is considered to be an active association. Its establishment was at the initiative of ORMVA/TF, but was not established as a khattara association like the others. Instead, they developed an Association for Rural Development, and selected as office members people who already had a high status in a traditional khattara organization. This is a type of association where the traditional khattara organization has obtained legal status as an Association for Rural Development through the registration process.

Challenges for Associations' Activities

Factors that determine the activeness of an association can be summarized as follows:

- Availablity of sufficient water volume in khattaras;
- Behavior of the inhabitants and water users;
- The size of the activity area within one village; and
- Existence of strong leadership.

It is needless to say that the existence of water flow in khattaras is the most important factor that determines the activeness of an association. Conversely, khattaras that have dried up do not become a choice for aid programs; and it is natural that such associations have no motivation for being active.

Typically, associations that are limited to a single village are more active. This is mostly driven by the sense of commonality of purpose and interest. Such motivation is lacking in associations that span more than one village. The commonality of cause was demonstrated in the El Amal Association in El Bouiya. In 1999 two khattaras, which had been the main source for irrigation in El Bouiya, were damaged by flood. The young people in this association made coordinated efforts to repair them, and through this work developed a spirit of collaboration and cooperation.

The existence of strong leadership is also an important factor that impacts the level of activity of an association. There are number of examples where the lack of such leadership has led to the corresponding associations becoming dormant or dysfunctional.

In many cases, activities of the associations are limited to seeking economic assistance from external organizations, even if they have other stated objectives in the declaration of their establishment. It is also documented that witnessing other associations receiving economic aid from external organizations was a primary moviation to establish their own association.

Because there are very few funding opportunities for khattara rehabilitation, there is a strong competition among the associations to get financial aid, and each inhabitant insists that their khattara (or khattaras) are badly in need of help.

This competition became more intense after some associations were successful in receiving economic assistance.

Conclusions

On the whole, many of the problems facing use and management of khattaras can be broadly classified as either caused by natural factors or by social practices and norms. There are many problems that are caused by societal behaviors, like pollution to irrigated lands by utilization of washing detergents and shortage of manpower due to exodus from rural areas. Comparatively, one may argue that these problems are much more serious when compared against those caused by natural factors.

A large part of these problems is driven by a change in lifestyle and way of thinking. Therefore, it may be necessary to take comprehensive measures to solve the problem. While technical assistance is important for khattara rehabilitation, simultaneous reinforcement of organization of water users is also very important for sustainable development of khattaras and regions. This reinforcement can be possibly achieved by the efforts of associations and assistance from external organizations. These associations, which represent a new concept of khattara management, can be considered to be evolving. One hopes that they will play an important role in khattara development in the future.

References

Benyahya, M. and A. Bouachik (2003) Le Nouveau Code des Libertés Publiques, Rabat, REMARD.

Ministère de l’Agriculture, du Développement Rural et des Pèches Maritime (1999) Strategie 2020 de Developpement Rural: Document de Reference, Rabat, Conseil Général du Développement Agricole.

ORMVA/TF (2003) Regional Agency for Irrigation and Agricultural Development of the Tafilalet, Errachidia, Morocco.

Oshima, K. (2001) "Utilization of Khattara and Organization of Water Users at Tizgaghin in Morocco", The Journal of Daito Asian Studies 2: 27-42.

Oshima, K. (2004) "The Future Prospects of Khattara and Roles of Organization of Water Users", The Journal of Daito Asian Studies 5: 59-72.

Traditional and Contemporary Water Harvesting Techniques in the Arid Regions of Tunisia

Mohamed Ouessar, Mongi Sghaier and Mondher Fetoui

Introduction

The Middle East and North Africa (MENA) region is by far the driest and most water scarce region in the world. Rapid population growth, increase of household income, and expansion of irrigation have exacerbated the situation. There is evidence that limited water availability is slowing down the economic and social development of MENA countries (Renard et al., 1996; Oweis et al., 2001).

The MENA region encompasses mainly poor, developing countries. They often do not possess the technical know-how, financial capacity or the institutional structures to adopt modern water management technologies. However, over centuries societies in this region have accumulated valuable knowledge and developed practices to cope with water shortages (Oweis et al., 2001; Ben Mechlia & Ouessar, 2004).

The southeastern region of Tunisia is extremely water scarce, with annual rainfall ranging from 150 to 230 mm. Areas, where traditional water harvesting techniques are applied, are limited (Bonvallot, 1979; El Amami, 1984). However, since the independence of Tunisia there has been a gradual expansion of cultivated fields, mainly olive trees. This development was supported by the construction of *tabias* and water spreading structures in the foothills and surrounding plains, exploited normally as rangelands. In parallel, the Soil and Water Conservation Service of the Ministry of Agriculture has further introduced modern technologies (gabion units, groundwater recharge wells, etc.) especially during the last two decades, which witnessed the implementation of the national soil and water conservation strategy and the water resources mobilization strategy (Ministère de l'Agriculture a & b., 1990).

The enrichment of the existing traditional techniques has raised the question of the nature of the linkages between the traditional and the newly introduced water harvesting technologies. Are they complementary or conflicting? What are the perceptions of the local communities of these changes in the landscape useage? What impacts (positive and negative) have they induced? What future prospects could be considered?

General Characteristics of the Watershed of Wadi Oum Zessar

The watershed of *Wadi* Oum Zessar is situated in the southeastern region of Tunisia, in the province of Médenine. It stretches from the south-west of the Matmata Mountains near the village of Béni Khdache across the Jeffara plain and into the Gulf of Gabès, terminating in the saline depression (*sebkha*) of Oum Zessar (Figure 1). The general characteristics of the study area are provided in Table 1.

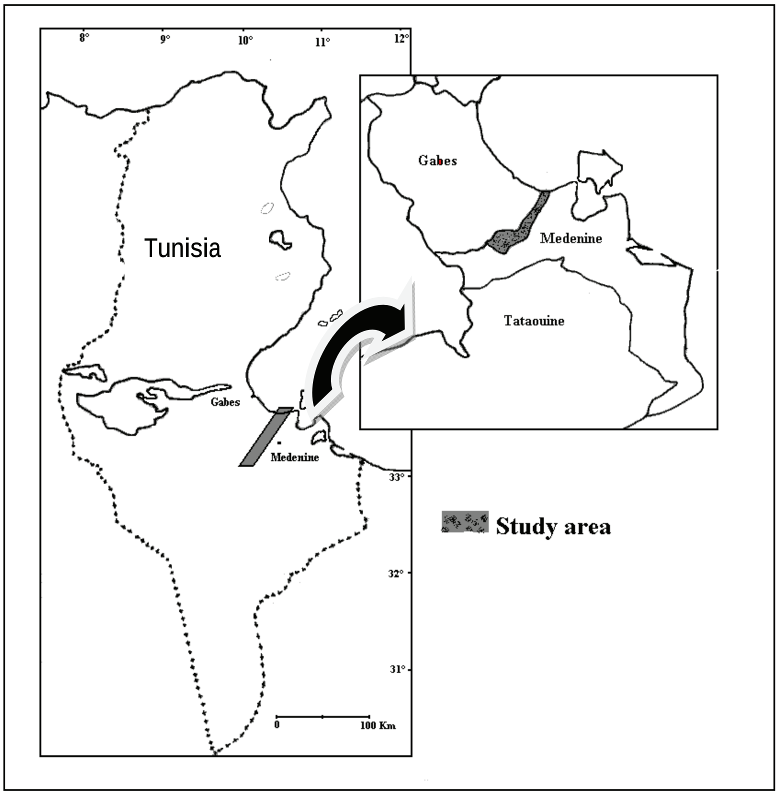


Figure 1. A map of Tunisia showing the location of the study site.

The climate in the watershed of *Wadi* Oum Zessar is predominantly of the Mediterranean type and is characterized by the continental, arid climate of the Matmata Mountains as well as the maritime, arid influence of the Mediterranean Sea. The temperatures in the study area range from as low as -3°C during the winter months (December to February) to 48°C during the hottest period of the year (June to August). The watershed is situated in an arid ecosystem with low annual rainfalls (between 150 and 240 mm) and high variability (both in time and space) (Derouiche, 1997). The 'wet' season stretches out over the months of November to February, and the remaining period is dry. The summer months are almost rainless. Highly intense showers (more than 50 mm/h) could occur at any moment during the period September to March (Fersi, 1976).

Table 1. General characteristics of the study site.

Area (km^2)	367
Annual rainfall (mm)	180
Mean annual temperature (°C)	20
Altitude (m)	0-690
Population (inhabitants)	24,188

The agricultural systems are marked by their diversity from the upstream to downstream areas of the watershed of *Wadi* Oum Zessar and are essentially characterized by:

- A non-regular agricultural production that varies from year to year depending on the rainfall regime;
- The development of arboriculture and the extension of newly cultivated fields at the expense of rangelands;
- The predominance of olive trees and the development of episodic cereals;
- The gradual intensification of the livestock husbandry systems; and
- The development of irrigated agriculture, exploiting surface and groundwater resources (Sghaier et al., 2002; Labras, 1996; Rahmoune, 1997).

The farming systems mainly encountered in the study are described in detail below (Sghaier et al., 2002).

The "Jessour" System

This system is mainly found in the upstream areas of the watershed in the mountainous zone of Beni Khédeche. This is an ancient system consisting of a series of stone and earth walls, called *tabias*, built across the stream beds of narrow valley watersheds. The *tabias* collect and retain soil washed down hillsides by torrential rains (200 mm tend to fall all at once), forming terraces in a stair-step fashion down the natural slope. The rainfall also collects on these steps and permits cultivation of olives and barley, the traditional crops, and sometimes apples, apricots, chickpeas, faba beans, lentils, watermelons and vegetables.

In the Matmata mountains, where there is higher rainfall, the *Jessour* system has allowed for the cultivation of figs, grapes and apples. This mountain area is marked by fruit arboriculture, most notably the olive. Annual crops such as cereals, vegetables and some annual crops (beans, small peas, etc.) are also occasionally cultivated. The cropping areas are extremely small and rarely exceeded 0.25 ha. Tree densities are relatively high and can exceed 60 trees/ha. On average, farmers own six parcels. Recent research (Labras, 1996; Sghaier and Chahbani, 1997) has revealed that the average annual agricultural income by farmer is estimated to be TND 1,195 (approximately USD 1,000) with almost 70% generated by vegetable production. The gross margin per hectare is relatively low, around TND 110 (approximately USD 90) (Labras, 1996). The yearly non-agricultural income is estimated at TND 200 (approximately USD 170).

System of Irrigated Perimeters

Two subsystems can be distinguished: private irrigated perimeters and public irrigated perimeters.

Private irrigated perimeters: This subsystem is based on surface wells. It can be found both in the upstream and downstream areas of the studied watershed. Cash crops, vegetables and fruit trees are produced, some of which in greenhouses. The cropping area varies between 0.2 and 10 ha (Rahmoune, 1997).

Public irrigated perimeters: This subsystem is situated in the downstream zone of the study area and is fed by tube wells that are typically drilled with government support. The water management is ensured by a collective interest association known as Association d'Intérêt Collectif (AIC).

The System of Olive Trees

This system is marked by the dry arboriculture dominated by olive trees. It is mainly encountered in the plain and in the piedmonts. The area varies from 5 to more than 45 ha. Other tree species are also cultivated, such as almond and apple, among others.

The Mixed Agropastoral System

This system combines rain-fed, marginal agriculture with a livestock husbandry component. It emerged because former pastoralists gradually transformed their land use systems by introducing an agricultural component, which became increasingly important at the expense of livestock husbandry. This system is mainly found in the downstream area of the studied watershed on fragmented areas, ranging from 25 to 85 ha. The livestock typically consists of 20 to 150 goats and sheep, and up to 100 dromedaries grazing in the saline rangelands of the *sebkhas* (saline depressions). The marginal agriculture occupies only small areas and the majority of the income is derived from non-agricultural livelihoods.

Water Harvesting: Description and Inventory

A wide variety of traditional and contemporary water harvesting technologies, such as terraces, *jessour, tabias,* cisterns, gabion check dams and recharge wells are used in the study area. Water harvesting in the studied watershed has a long history (Carton, 1988) as evidenced, for example, by the remnants of a small retention dam that dates back to the Roman era (Figure 2). The various water harvesting techniques found in the study area are described in detail below.

Terraces

Like in other regions of Tunisia and the world, terraces are constructed on steep slopes using small retaining walls made of rocks to slow down the flow of water and to control erosion (Oweis et al., 2001). It seems that this technique is the oldest adopted water harvesting technique in the watershed. However, most of the terraces are abandoned and only remnants are still found in the upper area of *Wadi* Nagab. They have recently been readopted for small-scale afforestation works or olive tree plantations in the mountain ranges (Figure 3).

Figure 2. Storage dam dating back to the Roman era near the village of Koutine.

Figure 3. New terraces on the jebel of Tajra.

Jessour

This is another ancient water harvesting system particularly widespread in the region of the Matmata mountains (Ben Ouezdou et al., 1999). Jessour are built in the inter-mountain run-off courses and consist of a series of stone and earth walls, called tabias *(*or *sed, katra)*, that are erected across the stream beds of narrow valley watersheds (Figure 4). The tabias collect and retain run-off water and silt washed down hillsides by rainfall, forming terraces in a stair-step fashion down the natural slope. The terraces are used for cultivation of fruit trees (olive, fig, almond, date palm, etc.), legumes (pea, chickpea, lentil, broad bean, etc.) and cereals (barley, wheat).

Tabias

Tabias are usually constructed on foothills, in particular in areas with rather deep soils and gentle slopes. A *tabia* is formed by an earth bund, reinforced from below by a stone wall, on the sides by a stone-lined spillway typically erected along contour lines, and at the ends by lateral bunds (Figure 5). Water is stored until it reaches a height of 20 to 30 cm and is then diverted, either through a spillway or at the upper ends of the lateral bunds. The *tabia* gains its water directly from its water storage basin (*impluvium*) or through diversion of *Wadi* run-off (Alaya et al., 1993). In general, annuals and fruit trees are cultivated on it.

Figure 4. A typical traditional *Jessour* of the region.

Figure 5. Newly installed *tabia* on the piedmonts area.

Cisterns

Cisterns, locally known as *fesquia* or *majel,* are built to collect and store rainfall. The water is used for different purposes including domestic consumption, irrigation and for livestock. In the study area, a cistern is simply a cement coated sub-surface hole (Figure 6). Cisterns with varying capacity (5 to 50 m^3) are found in the entire watershed of *Wadi* Oum Zessar.

Figure 6. Cisterns for drinking water and animal watering.

Gabion check dam units

These structures are made of blocks of galvanized nets (gabion) filled with rocks. They are built in the *wadi* beds (Figure 7). In general, they have the form of a rectangular spillway. They are used for the purpose of slowing down the run-off flow so as to increase the infiltration rate to the underground water tables and also in order to divert a portion of the run-off to neighbouring cultivated fields (*tabias*). These units are encountered as small check dams on the main intermittent water courses.

Recharge wells

When the permeability of the underlying bedrock is judged to be too low, casting tubes may be drilled into the wadi beds to enhance the infiltration of run-off water to the ground aquifer. In the watershed, these recharge wells were installed behind gabion units (Figure 8).

Figure 7. Gabion unit on *Wadi* Naguab.

Figure 8. Recharge well installed behind a gabion unit on *Wadi* Koutine.

Water Harvesting Realizations

Massive water harvesting projects were initiated in the province of Médenine, and particularly in the watershed of *Wadi* Oum Zessar, in the 1980s. The focus was on micro-watershed treatment and maintenance of existing structures in an area of approximately 36,000 ha (7,200 ha in the study area) and 39,000 ha (11,000 ha in the study area). Moreover, 270 recharge and spreading units (240 units in *Wadi* Oum Zessar) have been installed. Investments of TND 9.71 million (USD 8 million) were made for the province, TND 2 million (USD 1.6 million) in the study area (CRDA, 1998). At that time, the *Wadi* Oum Zessar represented a main focus for the implementation of the various practices undertaken. In fact, more than 70% of the water harvesting units have been installed in this watershed.

During the 1990-2000 decade, the regional services of soil and water conservation executed two main national programs, namely the Soil and Water Conservation Strategy and the Water Resources Development Strategy. The work undertaken mainly consisted of the construction of *jessour*, *tabias* and terracing (Figure 9). By the end of 2000, recharge and spreading units were built and recharge wells installed.

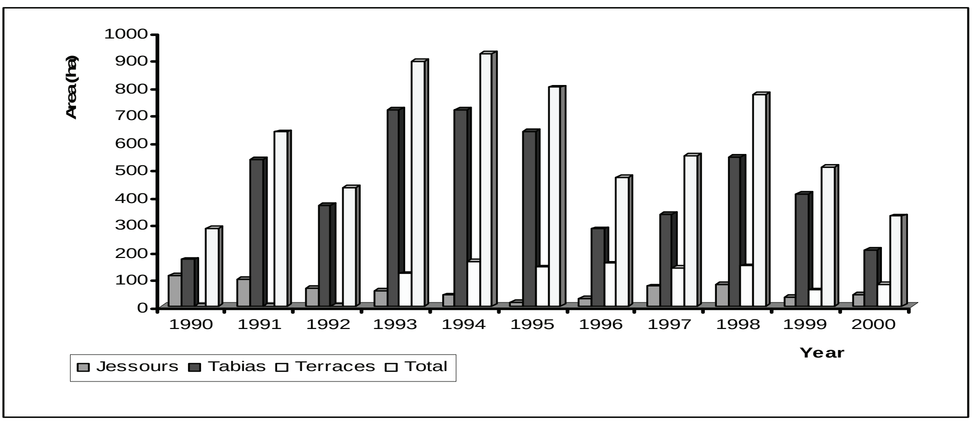


Figure 9. Work undertaken for the period 1990-2000.

Perception of Water Harvesting Techniques

The local community’s perception toward each water harvesting technique (traditional and modern) regarding its impacts on land production and productivity, and appreciation of the newly introduced techniques compared to the traditional ones, was studied. For this agro-socio-economic survey, the study area was divided into upstream and downstream areas. The results of the investigation are summarized in Table 2.

Farmers largely acknowledged the positive impacts of water harvesting technologies on groundwater recharge, siltation control and crop diversification. However, they remained skeptical on the role of these constructions with regards to yield improvement and run-off control. On the other hand, livestock herders were negatively affected by this intervention because the run-off water is almost entirely retained in the watershed. This resulted in reduced quality and quantity of the halophyte vegetation of the *sebkha* used as the main winter grazing area for camels.

Table 2. Farmers' appreciation of the water technologies impacts in the study area. The farmers were asked whether the works have resulted in a) yield increase, b) water erosion control, c) groundwater recharge, d) run-off reduction, e) flooding control, f) cropping diversification and g) biodiversity improvement. The farmers were divided in different groups as listed below. (Please note the symbols: ↑ - increase; ↓ - decrease)

Group	**Impacts of water harvesting (WH) technologies[a]**					
	Yield ↑	Erosion ↓	Recharge ↑	Run-off ↓	Flooding ↓	Diversification ↑
Beneficiaries of WH works	56%	100%	100%	33%	100%	100%
Irrigators with tubewells	87%	100%	100%	38%	75%	88%
Irrigators on surface wells	100%	100%	100%	50%	75%	100%
Herders	80% (rangelands)	60%	0% (species disappearance)	75%	100%	-
Fishermen	50% (of clovis)	100%	100%	75%	100%	-

[a]: *Expressed as a percentage of inquired farmers in favor of the statement.*

With regards to the preference of the different water harvesting technologies (*jessour*, *tabias* with natural impluvium, *tabias* on spreading units and gabions), the farmers reacted differently depending on their location in the watershed. In fact, in the upstream area, since the farmers are used to the *jessour*, the first preference (67%) is given to this technique, followed by the *tabias* and then the gabion. In the piedmont zones, however, the priority is given to *tabias* with natural impluvium (NA), *tabias* on spreading unit (SP), followed by *jessour*. In the downstream area, both *tabias* are ranked first (50%) followed by gabion and then *jessour*.

It is clear that the perception of the population of the used techniques depends largely on the tradition of the group and its location in the watershed.

Conclusions

In the arid regions of Tunisia, considerable investments are being made in maintaining the traditional water harvesting techniques and introducing new ones to capture the scarce amount of rainwater (100 to 230 mm annually) for agricultural, domestic and environmental purposes.

A large variety of traditional (*jessour*, cisterns, etc.) and contemporary (gabion, *tabias*, recharge wells, etc.) water harvesting techniques are encountered in the area. They have been playing various roles with regards to the exploitation of rainfall and run-off waters (soil water, vegetation, flooding, aquifer recharge, etc.).

The local population is, in most cases, aware of the environmental impacts of the introduction of new water harvesting techniques. Their perception depends largely on the agricultural activities they are involved in (i.e. rain-fed farming, irrigation, or livestock production, etc.) and the location of his fields/pastures in the watershed (upstream, piedmont, downstream, coast).

However, the wide range of possible (positive and negative) impacts that can occur as a result of the installation of the water harvesting structures is not fully understood (Ouessar et al., 2004). Furthermore, the interactions between upstream and downstream areas have to be studied in more detail as a basis to ensure equitable sharing of natural resources between different users.

References

Alaya, K., Viertmann, W., Waibel, Th. 1993. Les tabias. Imprimerie Arabe de Tunisie, Tunis, Tunisia. 192 pp.

Ben Ouezdou, H., Hassen, M., Mamou, A. 1999. Water laws and hydraulic management in southern Ifrikia in the middle ages (in Arabic) based on the manuscript ‘Land rights’ of Abi El Abbes Naffoussi (died in 1110). Centre de publication universitaire, Tunis.

Bonvallot, J. (1979) “Comportement des ouvrages de petite hydraulique dans la région de Médenine au cours des pluies exceptionnelles de mars 1979”, Cahiers ORSTOM, Série Sciences Humaines 16(3): 233-249.

Carton D. (1988) “Essai sur les travaux hydrauliques des Romains dans le Sud de la Régence de Tunis”, Bulletin Archéologique du Comité des Travaux Historiques et Scientifiques: 438-465.

CRDA (Commissariat Régional au Développement Agricole – Médenine) 1998. Rapport annuel. CRDA, Médenine.

Derouiche, R. (1997) Contribution à l'étude par modèle numerique de l'impact des aménagements de CES sur la recharge de la nappe de Zeuss-Koutine, Engineering Dissertation, Institut National Agronomique de Tunisie.

El Amami, S. (1984) Les aménagements hydrauliques traditionnels en Tunisie, Centre de Recherches en Génie Rural, Tunis.

Fersi, M. (1976) Caractéristiques hydrologiques du sud tunisien, paper presented at Séminaire sur la recherche scientifique et le développement des zones arides de Tunisie, 26-28 November, Tozeur, unpublished.

Labras A. (1996) Analyse comparée de l'opportunité technico-économique de l'oléiculture en plaine et en montagne dans le sud-est tunisien, Engineering Dissertaation, Ecole Supérieure d’Agriculture de Mograne, Tunisie.

Mechlia, B. and M. Ouessar (2004) "Water harvesting systems in Tunisia", In: Oweis, T., A. Hachum and A. Bruggeman (eds.), Indigenous water harvesting in West Asia and North Africa, ICARDA publications, Aleppo, Syria: 21-41.

Ministère de l'Agriculture (1990a) La stratégie nationale de la conservation des eaux et du sol (1990 - 2000), Minstère de l’Agriculture, Tunisie.

Ministère de l'Agriculture (1990b) La stratégie nationale des ressources en eau (1990 - 2000), Ministère de l’Agriculture, Tunisie.

Ouessar, M., M. Sghaier, N. Mahdhi, F. Abdelli, J. De Graaff, H. Chaieb, H. Yahyaoui, and D. Gabriels (2004) “An integrated approach for impact assessment of water harvesting techniques in dry areas: The case of Oued Oum Zessar watershed. (Tunisia)”, Journal of Environmental Monitoring and Assessment 99: 127-140.

Oweis T., D. Prinz and A. Hachum (2001) Water harvesting: Indigenous knowledge for the future of the drier environments, ICARDA publication, Syria.

Rahmoune L. (1997) Dynamiques des systèmes agraires du sud est tunisien, cas de la presqu'île de Djorf, MSc dissertation, Institut National Agronomique de Paris Grigon, France.

Renard, K.G., L.J. Lane, J.R. Simanton, W.E. Emmerich, J.J. Stone, M.A. Weltz, D.C. Goodrich, and D.S. Yakowitz (1996), "Agricultural impacts in an arid environment: Walnut Gulch studies", Hydrological Science and Technology 9(1-4): 145-190.

Sghaier M. and B. Chahbani (1997) Simulation on improvements of the traditional *jessour* systems and their impacts of farm income in arid zones of Tunsia : case of the micro-watershed of Ksar Joumaa (Matmata mountain), Working Paper, ICARDA, Cairo.

Sghaier M., N. Mahdhi, J. De Graaff and M. Oessar (2002), "Economic assessment of soil and water conservation works: case of the oued oum zessar watershed in south-eastern Tunisia", In: De Graaff J. and M. Ouessar (eds.) Water harvesting in Mediterranean zones: an impact assessment and economic evaluation. TRMP paper n° 40, Wageningen University, Holland: 101-113.

Karez in the Turpan Region of China

Qingwei Sun, Tao Wang, Iwao Kobori, and Luohui Liang

Turpan – An Oasis Supported by Karez

The Turpan oasis is located in the Turpan Depression, the second lowest point on the earth's surface after the Dead Sea. Turpan has a continental and hyper-arid climate with an average annual precipitation far less than the potential evaporation. In ancient times, the area was called 'Land of Fire', because average summer temperatures are higher than 38ºC.

The oasis at Turpan, located in the desert expanse of northwestern China's Xinjiang province, owes its surprisingly lush green environment to the karez underground system of water supply. For centuries the oasis has been the home to the Uighur, a distinct Turki-Mongol ethnic group.

Turpan has an interesting history. More than 2,000 years ago, the oasis was a strategic stop on the Silk Road – the major overland trade route linking China with India, Persia, and Rome (see Figure 1).

The area is well-known for its extensive water harvesting and channeling system, called *karez*, which orginantes from the Han Dynasty (200 BC). This irrigation system, which is sometimes referred to as the "Underground Great Wall", has provided the basis for agricultural activities in the very arid environment. Nowadays, there are still large stretches of fertile land irrigated by karezes that were mostly built during the last two centuries. Grape cultivation is the main land use in the oasis today. Many farms have drying towers for the production of raisins.

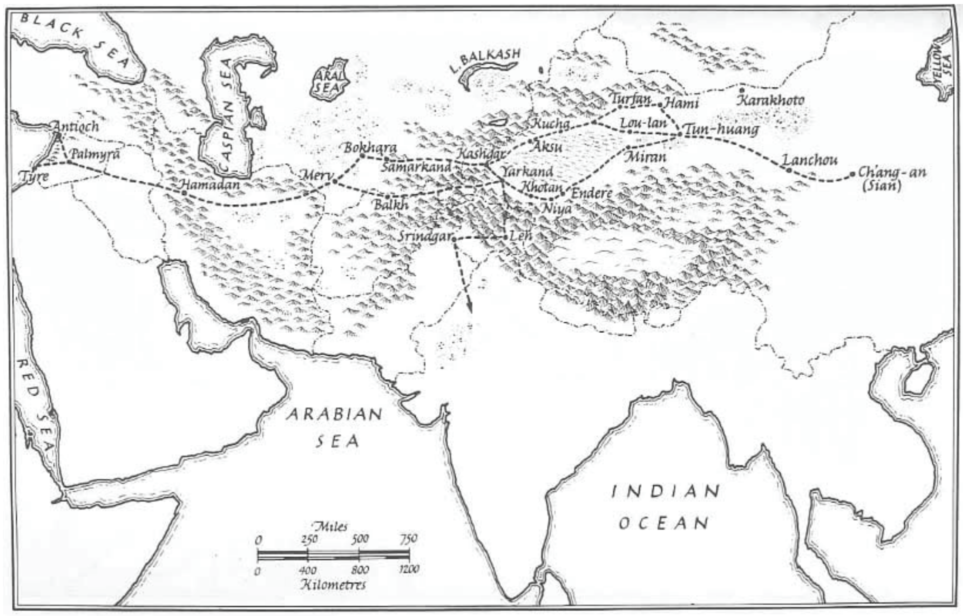


Figure 1. Main routes of the old Silk Road.

The Emergence of Karez in Turpan

The climate in Turpan is very hot and extremely dry. The Turpan Basin is one of the regions in China with the lowest precipitation (9 – 25 mm), far below the potential evaporation (about 3,000 mm). It is not unusual that there is no rain for a period of seven to ten months.

However, there are plenty of groundwater resources in the arid Turpan Basin which are recharged by melt water from the glaciers and snowfields of the nearby Tian Shan mountain range. The mountains are located north-west of Turpan and are over 5,000 m high. In the higher altitudes the annual precipitation is abundant, ranging from 800 to 900 mm. The karez system was designed to harvest, store and channel the valuable melting and flood water and provide irrigation water during the main growing season.

As there is a natural slope from the foothills at 900 m towards the deepest part of the Turpan basin at –161 m elevation, the topography of the area is favourable for this sophistacted irrigation system.

Thus, the combination of a desert climate, abundance of groundwater and suitable topographic conditions presented ideal conditions for the development of the karez system in the Turpan Depression. Some of the history of karez has been well documented in publications like: *the Proceedings of International Conference on Karez Irrigation* (1993); *Karez in Xinjinang* (2006); and *Turpan Chronicles* (1990).

Origins of Karez in Turpan

The origin of the karez system in Turpan is not entirely clarified. There are different hypotheses regarding when and by whom the system was introduced to the area.

Many Chinese historians report that the karez system was first documented near Xi'An, the capital of the Han Empire, during the Han Dynasty about 2,200 years ago. Accordingly, the karez technology was introduced to Turpan, when the area was occupied by the Han Empire. This theory is supported by the fact that the design of the karez system as well as the terminology for various parts of the karez are very similar in both regions.

On the contrary, the American scientist Huntington, who visited China at the beginning of the 20^{th} century, documented that karez was introduced from the Persian Empire along the Silk Road at a later date, during the 18^{th} century. This hypothesis was subsequently widely disseminated by authors in Europe and North America.

Nowadays, it is more and more widely acknowledged that the karez system has been developed in parallel in different places such as in Turpan, in the ancient Persian Empire, and during the Han Empire. It seems to be likely that local people simply designed similar irrigation systems in similar environments.

The Typical Structure of Karez in Turpan

Karez systems are very delicate irrigation systems made up of vertical shafts, underground canals, above-ground canals and small reservoirs. Melting snow from the nearby mountains is their main water source. Water is collected by vertical wells and conducted by underground channels to the oasis, where the water is collected for irrigation. A karez transports water mainly underground in order to reduce water loss from evaporation and to avoid pollution. A karez does not require any pumps, it runs from high to low ground owing to gravity alone.

Underground channels collect water from aquifers in pre-mountainous alluvial fans and conduct it to outlets in lower-elevation farmlands and settlements (Figure 2). While the length of these channels varies greatly from 3 km up to 50 km, they are typically about half a meter wide and up to 2 m high.

Every 30 to 50 m, there are vertical shafts that are needed for ventilation and maintenance of the karez. The vertical shafts are about 90 m deep at the higher parts of the karez, with their depth gradually decreasing towards the lower parts. A storage pond located at the end of the horizontal channel stores excessive water during the snow melting season. These reservoirs provide a stable water supply for irrigation and domestic use over the year. From there, irrigation channels divert the water to the fields.

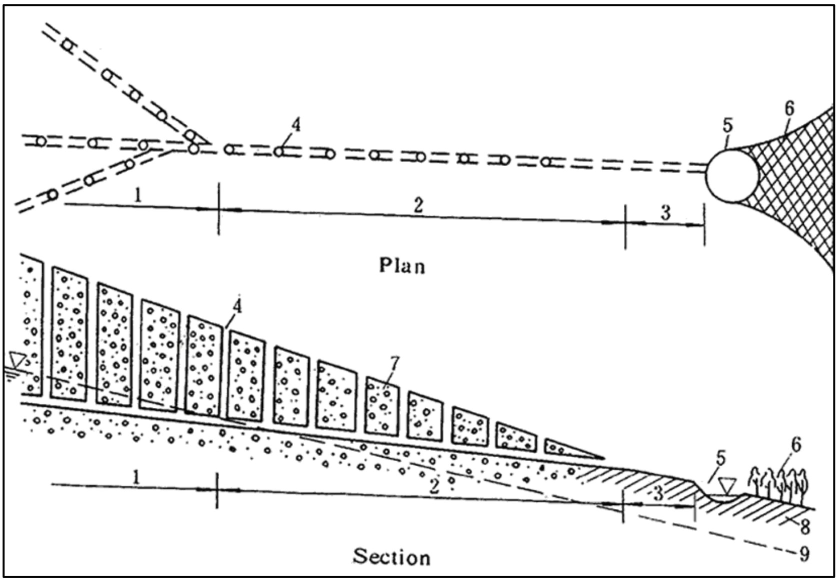


Figure 2. Schematic side and top views of a karez showing *(1)* a water harvesting underground tunnel, (2) a water-conducting underground channel, (3) an open channel, (4) vertical wells, (5) a small storage pond, (6) the irrigated area, (7) sand and gravel, (8) layers of soil, and (9) the groundwater surface.

Figure 3. A bird's eye view of the karez system in the Turpan Oasis (photo courtesy of Geroge Steinmetz).

The Construction and Management of Karez

Karez are constructed manually, and the construction can take up to eight years. The techniques and tools have remained almost unchanged over 2,000 years (please see Figures 4 and 5). The process begins with the digging of vertical shafts, which are then linked by an underground channel. Finally, the storage ponds are built and connected to irrigation channels.

Figure 4. Digging a vertical shaft (photo courtesy of Geroge Steinmetz).

It requires a lot of time and effort to maintain the karez system (see Figure 6). Traditionally, the underground channels were covered by trees, straw and soil to prevent flooding, contamination from sand, and freezing. This kind of cover is cheap, but has its drawbacks – it collapses frequently, blocking the channel. A better, but certainly more expensive solution is to use a cement cover. Often, when channels collapse, new sections are built to by-pass blocked passages.

Figure 5. Construction of a karez in Turpan, Xinjiang, China.

Figure 6. Cleaning an underground channel (photo courtesy of Geroge Steinmetz).

The Value and Status Quo of Karez Systems

In the Turpan Depression, the karez irrigation system has maintained a big oasis with tens of thousands of hectares of farmland, maintaining the livelihoods of thousands of people. Without the karez system, the landscape would be desert. In 2003, there were still about 400 karezes in operation, providing a total annual water supply of 230 million m^3 for the irrigation of about 8,800 ha farmland and domestic use for 60,000 residents.

Karez is a unique engineering relic, which has preserved ancient indigenous knowledge of hydrology and engineering. Nowadays, the karez systems in Turpan attract thousands of Chinese and international tourists. A karez museum has been established to display and explain the karez system.

Despite its long history which is believed to have started some 2,000 years ago, the peak period of karezes in the Turpan Basin was from the mid-19th century to the mid-20th century. In the 1950s, there were about 1,300 karezes with a total length of 4,000 km providing approximately 700 million m^3 of water and irrigating 24,000 ha of farmland. However, despite its high value for the region, on average 20 karezes have been abandoned every year since the mid-1960s. Today, the majority of karezes have fallen into dis-use and have dried up. Only about 400 are still operational, the supplied water volume decreased to 170 million m^3 (Figure 7).

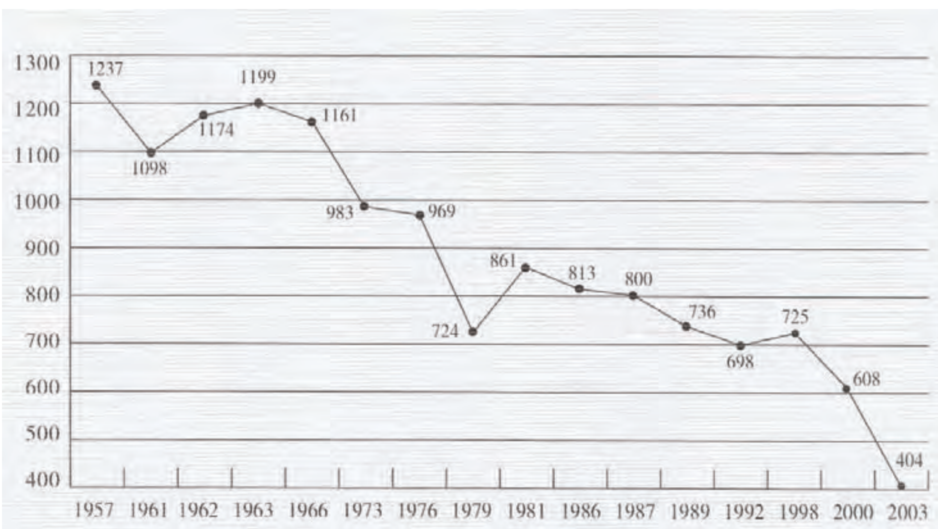


Figure 7. The decline of karez.

There are a number of reasons for the decline of the karez system in the Turpan oasis. First, rapid population growth and expansion of farmland since the 1950s has greatly increased the water demand in Turpan. At the same time, oil mining has become the major industry and has additionally augmented water consumption. In order to meet the increased water demand, reservoirs were constructed upstream, cutting off the karezes from their water source. At the same time, the increasingly wide-spread use of electrically-powered pumps has resulted in a decline of groundwater levels below the level of karez channels.

Conclusions

Karez is a unique and fascinating irrigation system with a long history in the Turpan oasis. It provided water for domestic consumption and agriculture and maintained a unique ecosystem in the desert. However, nowadays the karezes are increasingly abandoned and are not being maintained. This is partly due to the fact that the value of karez is not well understood. It is concluded that the government and local communities should join efforts to preserve and restore this ancient irrigation system.

References

Urumuqi (1990) Turpan Chronicles. Xinjiang People's Publication House. Urumuqi, China.

Urumuqi (1993) The Proceedings of the International Conferences on Karez Irrigation. Xinjiang People's Publication House, Educational and Cultural Press Ltd. Urumuqi, China.

Urumuqi (2006) Karez in Xinjinang. Xinjiang Karez Research Society. Xinjiang People's Publication House, Urumuqi, China.

Zarh-Karez: A Traditional Water Management System Striving Against Drought, Increasing Population, and Technological Change

Faisal Farooq Khan

Introduction

This chapter discusses the root causes that have resulted in the desiccation of 40 out of 50 karezes in the Loralai District of Balochistan Province in Pakistan. Zarh-Karez, as one of the fifty karezes in this district, is analysed in more detail to explain the political, economic and social challenges that most of the karezes are facing. In addition, the chapter sheds light on the major factors that have enabled karezes to maintain their resilience throughout a severe drought from 1996 to 2003.

Extreme population growth is the major challenge that the Loralai District faces. In order to address the rising demand for food, the Government of Pakistan introduced electric-powered tube wells to boost agricultural production. This has resulted in a dramatic declince of groundwater tables. In some areas, the groundwater tables dropped from 100 m to more than 300 m, negatively affecting the traditional water management system.

Background Information About the Study Area

Population and society

The overall population of the Zarh village and Loralai district has doubled in twenty years and the population of Loralai is expected to increase beyond the one million mark by 2015. Population growth in Loralai is attributed to three major factors. First, the lifestyle of the local population has rapidly improved due to remittances made by overseas Pakistanis. Second, agriculture has expanded significantly through the sale of fruit produced by thousands of orchards in the district. Third, inside Afghan refugee camps, trade flourishes and contributes to significant increases in household incomes.

Gender roles and literacy

The involvement of women in natural resource management is mainly limited to tending livestock, grinding wheat and managing drinking water supplies, as a Pashtun woman's mobility is largely restricted to her family's compound. Children and village males gather fuel wood for cooking. Literacy rates in the village are low: 36.21% for males and 1.3% for females.

Droughts

Droughts are the major natural phenomenon in the area that affect lives and agriculture. It has been observed that the duration and severity of droughts is increasing, whereas the intervals between them seem to remain unchanged. The latest drought was the most severe and the longest, lasting for seven years from 1996 to 2003. 20 years earlier, there was also a drought period for four years from 1972 to 1976, preceded by a two-year dry spell from 1950 to 1952.

Irrigation and agriculture

Around the village of Zarh, villagers have access to about 900 acres of cultivable land and another 900 acres of rangelands. About half of the cultivated land is irrigated by the Zarh-Karez, while tube and open wells irrigate the remaining land and also ensure drinking water supply to all households. *Sailaba*, another indigenous irrigation practice that diverts torrents from hills to depressions, has practically fallen into dis-use in recent years.

Prior to the advent of tube wells in the region in the 1960s, livestock grazing and rangeland management was the main livelihood activity. After a century of pastoral lifestyle, in early 1970, the Government of Pakistan fostered rural electrification and provided electricity to hundreds of thousands of villages in various parts of the country. By 1972, the policymakers and planners chose electricity-powered tube wells as a single remedy to address the major challenges in the province, including water shortages, food insecurity and unemployment. This investment boosted fruit production and exports in the province, but resulted in a decline of groundwater levels.

Government policies affecting land use

In the last thirty years, the domestic, market catered to agricultural policies that promoted cultivation of water-intensive, exotic species of fruits and vegetables. At the same time, policies supported the installation of thousands of electricity-powered tube wells and windmills in areas still without electricity. This practice became detrimental for groundwater resources, particularly during the drought from 1996 to 2003. In some parts of the province, water tables dropped from 25 m to below 300 m. Nevertheless, no intiatives of drought mitigation were implemented.

At the same time, agricultural policies precluded cultivation and seed improvement of drought-resistant indigenous species like almonds, pistachios, pomegranates, dates and olives, even though markets for such produce exist overseas. Livestock and rangeland management, an old tradition of the tribesmen in the district, was entirely ignored by the government policies.

The government's much appreciated 'open passport' policy to export unskilled and semi-skilled manpower to the Gulf region contributed to an increase of buying power, resulting in consumption patterns that have added pressure on the already over-stressed natural resources.

The Historic Development of Karezes

A typical karez consists of a mother well, an underground tunnel, a number of vertical shafts at a distance of 40 to 50 m from each other, and an outlet. An open on-farm water channel then connects the karez to the farmland. The length of a karez may vary from 300 m to 15 km. *Hazarawal* (Persian speaking residents of Central Afghanistan), famous for their specialist skills, typically construct karezes. Villagers are responsible for the maintenance and operations of the karez while the farm owners seasonally clean and desilt the karez channels.

The earliest historical evidence of the presence of a karez in Balochistan dates back to 2,700 years ago. By the time of independence of Pakistan in 1947 and before the 1950-52 drought, 22,000 karezes were operational in Balochistan. Fifty years later, 12,000 karezes were still functional, but today only less than 4,000 karezes have survived the latest drought from 1996 - 2003, which was also the longest and most severe drought in the history of Pakistan.

The provincial government of Balochistan, with the assistance of the Government of Pakistan, has recently completed the rehabilitation of 105 karezes in the province. The rehabilitation work was limited to the widening of mother wells, repairing the vertical shafts, desilting of channels, lining of on-farm distribution channels, and finding alternate sources of water for the dried karezes. Three delay action dams were built in the province to recharge karezes, but they all ran dry before the monsoon season approached.

The Department of Food and Agriculture is responsible for the karezes, because karezes are managed in conjunction with farmlands. Although the functionality of karezes is closely related with the condition of surrounding forests and rangelands in the catchment area, the Forest Department is kept aloof of karez rehabilitation attempts.

Karez Management Practices

Each clan of a tribe has its own karez. The user rights are determined by tribal affiliation and not by the duration of residence in a village. The operation and management of a karez is the responsibility of the water users. Normally, the head of a village, the *malik* (village head), is the person in charge of karez water distribution and management. Allocation of water quotas is generally based on centuries-old, verbal agreements amongst the first settlers. New quotas are only negotiated when new occupants settle down in an abandonned village. A classic example is the settlement of the nomadic Kakar tribe during late 1890s or early 1900s in Loralai to replace Hindu and Sikh families driven out by British rule.

Land is allocated among all men who have contributed to the construction of a karez. For example, if ten male persons have constructed a new karez or settled in an abandoned village with a karez that irrigates 100 acres of land, then ten acres of land will be allocated per male person. These men and their offspring will keep the land and water use rights associated with it as long as the clan lives in the village. Inheritance and number of offspring resulted in varying sizes of land owned and shares of karez water.

Simple measurement techniques are used to allocate water distribution quota. Interestingly, measurements of water distribution are time-based. According to a local malik, droughts are a regular phenomenon in the area and their ancestors were aware that quantification of water by volume would lead to conflict during the droughts. Allocation of water by time ensures some water for everyone.

The largest measurement unit of water is called *shabana roz* and corresponds to a day and night discharge of water from a karez channel into a landholding. A shabana roz varies from village to village depending on the size of the water gauge. There is no standard measurement of a shabana roz or standard relation with a particular size of farmland. However, there is a standard shabana roz at the village level and smaller units of water measurement are derived from that standard measure.

Figure 1. A water channel connecting a karez with the farm.

Clearly, a shabana roz discharge from the same karez equaling the same amount of water can serve very unequal sizes of land in two neighboring villages. For example, one shabana roz of water in the Zarh-Karez area is used for irrigating 270 acres of farmland, while just a few kilometers away one shabana roz is used for irrigating only 10 acres.

Table 1. Overview of how water is measured by time and size of farmland without any consideration to its volume.

Measurements	Duration	*Sargarah* Land size	Zakhpail Land size
Shabana roz	24 hrs	350 acres	400 acres
Horr	12 hrs	175 acres	200 acres
Chareek	03 hrs	44 acres	50 acres
Chareekee	1.5 hrs	22 acres	25 acres
Gutt	45 mns	11 acres	12.5 acres

Furthermore, a landowner possessing land near the outlet or head of the distribution channel will get water first regardless of the size of his quota, whereas a landholder at the tail of the water distribution channel will receive his share in the end, even if he has the largest landholding in the village. The malik ensures that all landowners receive their allocated quota of irrigation water.

Land Classifications

In the district, land is categorised into four major categories: *mazrua* (cultivated), *ghair mumkin* (uncultivable wasteland), *banjar jadeed* (new cultivable wasteland), and *banjar qadeem* (old cultivable wasteland). Changes in the distribution and share of land use categories, though not officially recorded since 1966, have occured.

Figure 3. A glimpse of an orchard irrigated by a karez.

Mazrua or cultivated land in Zarh and other villages had on average expanded by less than 10% in the last thirty years. Old mazrua land is irrigated mostly by one karez, as the entire socio-economic and socio-political structure of a clan depends on the karez management practices and distribution of its water.

The main agricultural expansion has occurred in banjar jadeed and to some extent in banjar qadeem. Expansion of agriculture in the above two categories of land has not affected the existing karez water quotas and mazrua land ownership. Different traditional irrigation (*sailaba* and *khushkaba*) methods and electric powered tube wells are used to irrigate this land.

Distribution of ghair mumkin has not changed significantly. However, the droughts of 1950-1952, 1972-1976, and 1996-2003 have transformed some of the banjar qadeem land into ghair mumkin as part of the desertification process.

Since 1966, change in the land cover of mazrua and banjar jaded categories of land has mostly occurred due to human activities, whereas change in the land cover of banjar qadeem and ghair mumkin has occurred mostly due to climatic changes. Distribution of the first two categories of land was made according to the available manpower and with the clan's consent as decided upon in a jirgah.

Table 2. Land use trends practiced in seven villages (including Zarh, Chinjin, Shah, Surki Jungle, Chapli, Dargai Sargarah and Dargai Zakhpail) in the Loralai Province according to the four land classifications.

	Land Classifications			
	Mazrua	***Banjar Jadeed***	***Banjar Qadeem***	***Ghair Mumkin***
Irrigation	Mainly Karez Where possible, tube wells, hand pumps and open wells	Sailaba and/or Khushkaba Surplus water from a karez, if available	Khushkaba	None
Cropping	Orchards, grains, cotton, and vegetables	Vegetables and grains	Grains	None
Livestock	Stall feeding	Grazing	Grazing	Grazing
Housing	Mainly	Some	None	None
Ownership and access	By inheritance only. Not sellable outside the clan.	Shamilat Awara	Shamilat Awara	Shamilat None

Social Factors Contributing to the Survival of Karezes

Social cohesion and homogeneity of communities inhabiting the villages in the karez area were identified as the major factors ensuring sustainable management of a karez. As mentioned earlier, a karez is a communal holding that is used by everybody who belongs to the same clan of a tribe. This means that the operations and management of the karez are also the responsibility of all the villagers who irrigate their lands using karez water. When the karez needs to be repaired, all users must contribute according to their water share, either financially or in-kind.

To operate such a system of interdependency, strong social bonds and mutual trust are required. This is precisely what was witnessed in the case of successfully operated karezes such as Dargai karez and Chinjan karez. Inhabitants of the villages of both karez areas are from the same clans and have been living there since more than a century. On the contrary, Zarh-Karez, however, is under the jurisdiction and managed by different clans. This has resulted in social conflicts and parts of karez has dryed out, because only one of the clans still manages and maintains their share of the karez system.

Some villages rely entirely on their karez for irrigation, simply because karez water is most cost-effective. This was observed particulary in villages without large land holdings and where traditional farming practices still prevailed over progressive cultivation systems. Obviously, without alternative water supply systems, these villagers have strong incentives to maintain their karezes.

The government's interventions also contributed to the rehabilitation of karezes, because delay action dams were built to support recharging Zarh and Dargai karezes.

Factors Contributing to the Decline of Karezes

Several factors have severely affected the traditional water management system in the semi-arid region of Loralai.

First and foremost, many karezes dried up due to the drought experienced by Balochistan for eight long years. Thus, natural processes were one of the strong underlying causes for the decline of karezes. However, it needs to be noted that the government failed to make use of the excess water available during wetter periods. In addition, rural electrification and broad installation of electric tube wells as subsidized by the government resulted in a significant depletion of groundwater levels.

Agricultural development has also played a role. The agricultural sector started booming all over the country as a consequence of agricultural modernization; large orchards of exotic fruit trees were established everywhere in Balochistan. Agricultural subsidies fostered the cultivation of cash crops such as apples, grapes, and onions. However, these crops were not adapted to the arid climate in the Balochistan province and their cultivation proved to be very water-intense. Limited groundwater resources were over-exploited to satisfy the water needs of the new crops.

Furthermore, mass labour migration both in and out of Pakistan generally improved income levels. The resulting improvement of living standards contributed not only to a rapid population growth, but also led to changes in consumption patterns. Increasing demand for food and agricultural products was the outcome. This was an incentive for many farmers to increase the size of their farmlands. However, as their shares of the karez did not simultaneously increase, tube wells and other irrigation facilities were installed and increasingly substituted the traditional irrigation system.

Lastly, the influx of more than one million Afghan refugees additionally affected the karez water management and increased the pressure on the natural resource base. Pakistan communities were moved away from the Afghan border, making it difficult to maintain the management of the karez system. Zarh-Karez alone has become home to 22,000 Afghan refugees and internally displaced Pakistanis from the villages near the Afghan border.

Conclusions

In Balochistan, indigenous water management practices are regarded as the only way to re-establish integrated water resource management fundamental for the survival of people in this arid region of Pakistan. Thus, efforts should focus on rehabilitating karezes in an integrated approach and responding to the needs of local communities. Grassroots institutions will have to be revived for re-engaging people in karez management. Water-efficient and marketable indigenous species should be re-introduced in the karez areas and their cultivation should be fostered. Community-based disaster management plans for drought mitigation and flood control will need to be developed. Moreover, the unregulated use of tube wells and construction of ill-planned dams and reservoirs will have to be stopped immediately.

Traditional Water Distribution in Aflaj Irrigation Systems: Case Study of Oman

Abdullah S. Al-Ghafri

Introduction

The Sultanate of Oman is located in the southeast of the Arabian Peninsula (Figure 1). On a total area of approximately 310,000 km^2, Oman has a population of 2.2 million (Ministry of Information, 1997). Oman has a hot climate and is humid in the coastal areas, but is very dry in the interior. Average rainfall is 100 mm, except for in the south region which has a period of intense monsoon rainfall.

After oil, agriculture is the major economic sector for Oman, even though more than 80% of the land is desert. With 100,000 ha of cultivated land, the Sultanate is one of the major agricultural producers in the Arabian Peninsula, particularly regarding livestock production. However, only a very small percentage of land can be classified as agricultural land. Agriculture depends entirely on irrigation and more than one-third of the water used for irrigation is supplied by the traditional irrigation system called *aflaj*.

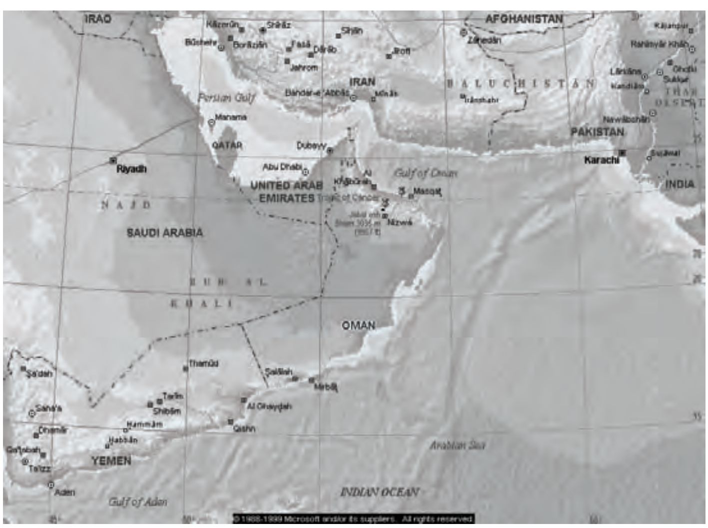


Figure 1. The location of the Sultanate of Oman.

Agriculture and Water Resources in Oman

In Oman, agricultural land is classified according to the following agro-climatic regions:

Musandam and Madha: Musandam is located in the extreme north of Oman, while Madha is a small, secluded island within the United Arab Emirates. Musandam is slightly wetter than most parts of Oman, with an average rainfall of 180 mm. The source of water is entirely from wells, but people additionally store rainwater in cisterns. Due to the limited groundwater resources, the agricultural area is threatened by salt-water intrusion. In Madha, the traditional irrigation system, *aflaj*, is the major water source.

The Btainah Coastal plain: This area has an average annual rainfall of 76-100 mm. It is the major agricultural region of Oman, responsible for 60% of the agricultural production in the Sultanate. Agriculture in this area is entirely dependent on irrigation.

The interior of Oman and Dahira plains: This region has an annual rainfall of less than 100 mm and is very hot. 50% of the land is irrigated by aflaj. Recently, a huge freshwater aquifer was discovered and the government has started developing its use.

*The mountain range of Jebel Akhdar:*This mountain range reaches a maximum altitude of 3,000 m and has an annual rainfall of 300 mm. The Jabal Akhdar plateau has a very unique climatic zone in Oman that enables cultivation of peaches, apples, pears, apricots, and almonds.

Sharqiyah plains: These plains are very dry and most of its agricultural land is irrigated by aflaj.

The Salalah plain: Located in the south of Oman, these plains receive an average annual rainfall of 70-360 mm. In this area, coconut cultivation dominates. The main water source for irrigation is tube and dug wells, while aflaj contribute to a lesser degree.

The Dhofdar Jebel: This region is located in the south of Oman. With its highest annual rainfalls in Oman (600-700 mm) due to the monsoon rains, these highlands provide good grazing land for cattle and goats.

The Najd: This a desert land in the southern part of Oman with poor soils and low water quality. However, it has a huge water aquifer, which is under development for agriculture.

Aflaj Irrigation Systems of Oman

Aflaj definition, distribution and history

The agriculture of Oman is almost fully dependent on irrigation (Abdel Rahman and Abdel Magid, 1993), because most crop-producing areas receive only between 100 to 200 mm of rainfall annually (Norman et al., 1998 a, b). The ancient aflaj irrigation system still plays a major role.

Falaj (singular of aflaj) is a canal system constructed above or underground to collect underground water, water from natural springs, or water from the baseflow of wadis. Aflaj provide water to farmers for domestic and/or agricultural use. The term falaj is derived from an ancient semitic root, which has the meaning to divide, reflecting that the water shares in aflaj are divided between the owners (Wilkinson, 1977).

Typically, a farming community owns all falaj water. Each farmer receives a share of the water depending on the size of his farmland(s) and his contribution to the construction of a falaj. Aflaj vary in size, ranging from smaller ones owned by a single family to larger ones that supply water to hundreds of owners. Although most aflaj in Oman are fully owned by farmers, there are some aflaj that are the government’s property (Wahby and Al-Harthi, 1995) or are communally owned, serving, for example, mosques, or are contingency reserves (Al-Abri, 1980). Many villages and towns in Oman have more than one falaj system.

Aflaj technology was adopted in Oman 1,500 to 2,000 years ago (Sutton, 1984) and some of these systems date back to the times of the Persian occupation of Oman (Wilkinson, 1977). Comparable systems of irrigation have emerged and still exist in many places around the world: Afghanistan, China, Iraq, Iran, countries of the Arabian Gulf, Jordan, Syria, Cyprus, North Africa, Spain, Sahara, Japan, Yemen, and the Americas (Cressey, 1958; Sekai no Kangai, 1995). Some two dozen variants of names of these systems exist, including quanat; karez (southwest Asia); khettara (North Africa); and falaj (Arabia).

Types of aflaj

Aflaj in Oman are classified into three types according to their water source; *ghaily*, *daudi*, and *ainy* aflaj.

Ghaily aflaj represent 50% of the total aflaj in Oman. Their main source of water is the baseflow of wadis (Figure 2). Typically, the canal has a length of 200-2,000 m.

Daudi aflaj represent 25% of the aflaj in Oman. Their source of water is a mother well. Similar to the quanat of Iran, water in this aflaj type is conducted from deep water tables by an underground tunnel or channel system (Figure 3). Compared with other types, daudi aflaj have the most stable flow rate around the year. The channel of the falaj can be as long as tens of kilometers and, therefore, local people opened access shafts for air circulation and maintenance. Large aflaj can have more than one mother-well.

In the *ayni aflaj*, the source of water is a natural spring, called *ayn*. The ayni aflaj represent 25% of the aflaj in Oman. The length of the canal can be up to one kilometer.

Figure 2. A Ghaily *falaj* in the village of Nakhal (photo: November 2001).

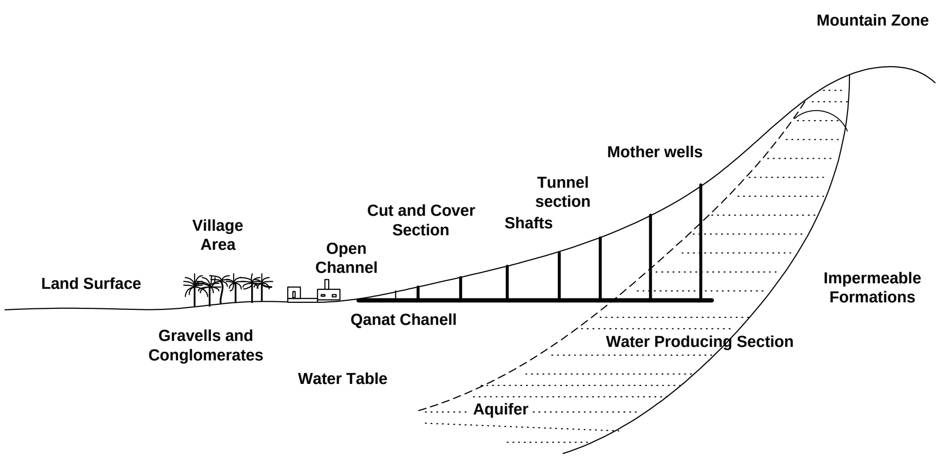


Figure 3. Cross section of a *daudi falaj* (*qanat*) in the piedmont zone (after Wilkinson, 1977).

Falaj water utilization

The aflaj systems are designed in such a way that domestic water demand is primarily served, followed by a supply of water for agricultural land. In most aflaj, the water is first directed to private households to meet drinking water demands. The water is then conducted through mosques, men's and women's public baths and finally to areas where water is needed to wash dishes and clothes. When domestic water demand is met, falaj water is used to irrigate the permanent cropland, mostly date palms, and, with the least priority, the seasonally cultivated land with wheat, tomato and onion (Al-Ghafri et. al., 1999, 2000a, 2000b). This arrangement helps farmers to control drought and guarantees basic crop production. Besides the agricultural and domestic use, aflaj systems are also sometimes used for industrial and other purposes, such as for water mills or to store water for travelers (Costa & Wilkinson, 1987).

Falaj administration

A typical large Omani falaj administration consists of a director (*wakil*); two assistants (*arifs*), one for underground-section services and the other for above ground-section services; an accountant (*qabidh*) or administrator (*aldaftar*); and a laborer (*bayadir*) (Al-Marshudi, 1995, Sutton, 1984). Depending on the size of the falaj system, aflaj can have all of the above administration, but at the very least they will have a wakil who is elected by the owners of the falaj and nominated by the head of the village (*sheikh*).

As the executing director, the wakil is in charge of the overall management of the falaj and is responsible for water distribution, leases, budget allocation, conflict resolution between farmers, emergencies etc. The arifs implement the wakil’s directions, supervise the laborer and may determine the timing of the irrigation. Under the supervision of the director, the qabidh controlls the falaj income, updates the falaj accounts and prepares annual financial reports to the falaj owners. Some portion of the aflaj water can be leased short- or long-term. This is controlled by the auctioneer (*dallal*).

If a conflict occurs, either the wakil or the owners can complain to the sheikh. If the sheikh cannot solve the problem, they or the sheikh himself will take the matter further to the governor (*wali)* who is the government representative and in a position to refer the matter to the judge (*qadhi)* for reaching a final decision. Sometimes the wakil or the owners call for an audit committee to check the financial income and expenditure of the falaj. This committee usually consists of 3 to 4 trustees from the village (Al-Saleemi and Nabeel, 1997).

Falaj Water Distribution

In Oman, the method of allocating water shares among farmers is complex and differs from one place to another (Abdel Rahman and Omezzine, 1996). In most aflaj of Oman, water is distributed based on time, but water allocation based on volume also exists in a few cases. Four different water allocation methods are described below.

1. *Time intervals*: In some aflaj systems, the day is divided into estimated intervals, according to which farmers share the water. For example, the full day can be divided into seven intervals, using events such as dawn, sunrise, midday, afternoon prayer, sunset, evening prayer and midnight. However, this method is not very popular because the time units are too variable and unclear, often resulting in conflict between farmers (Al Abri, 1980).

2. *Tasa*: In the northern part of Oman a different, more sophisticated method of water distribution is used. The principle is very simple - one unit of water share (*tasa)* is determined by the time needed to fill a container with water (Figure 4). Each farmer will get a multiple or division of one tasa. The volume of the container varies according to the time unit.

3. *Liggil*: In some parts of Oman, usually in the mountains and particularly in small falaj systems, the falaj water is stored in a large water tank (*liggil*). Water is then distributed by volume according to the size of the farmland(s). Typically, in such falaj systems, the flow rate is very low and land shares are small (Figure 5) (Al-Ghafri et al., 1999, 2000b).

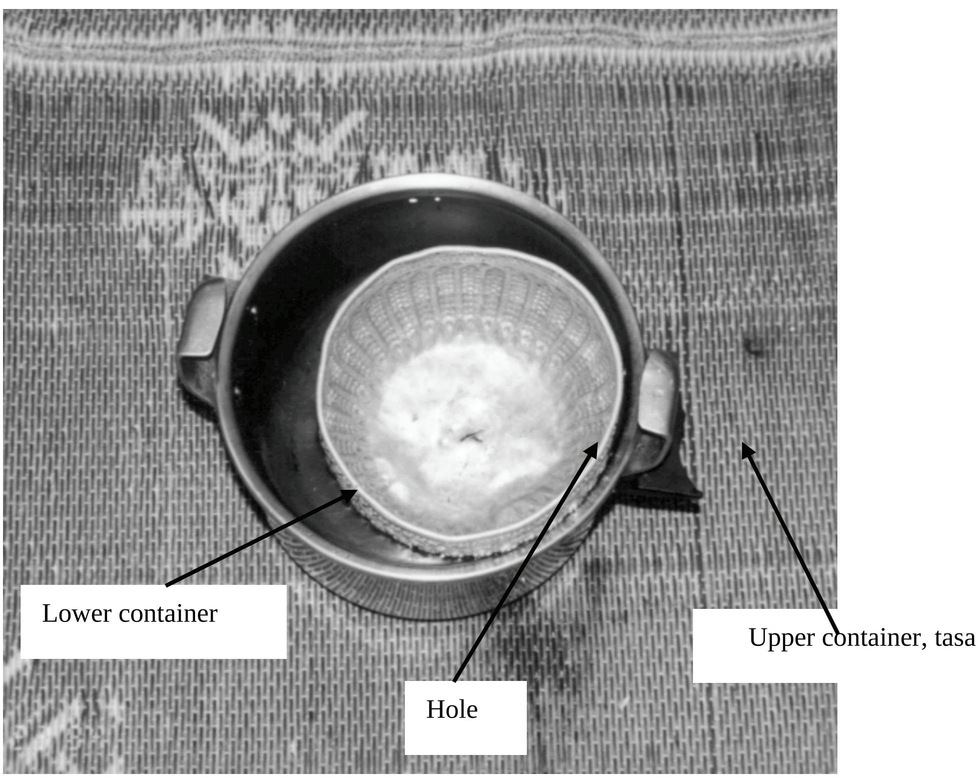


Figure 4. Tasa of *falaj Saiq* at Jabal al Akhdhar.

Figure 5. Liggil water tank for water distribution.

4. Athar: Athar is commonly used in all of northern and central Oman. It is one of the most complicated systems for allocating water among users. A farmers' committee is established to decide on the distribution of falaj water shares among falaj owners. The committee investigates in detail the flow rate, water flow fluctuations, soil type, number of owners and their proportional contribution in constructing the falaj, etc. Based on their findings, the length of the irrigation cycle (*dawran*) is determined. This can range from 4 to 21 days. Typically, the lower the flow rate, the shorter the dawran.

After the dawran is set, the water share for each farmer is determind using the time based unit of *athar*. Typically, each full day consists of 48 athars and two *baddas*, one for the day and one for the night. Each athar is further divided into 24 *qiyas*, which is practically the smallest unit of water share and approximately equal to the time required to irrigate one date palm tree with good falaj flow (Al-Ghafri et al., 1999). However, other units exist, representing different periods of time.

Once the water is divided between the shareholders, this distribution never changes and land and water shares are inherited among family members according to Islamic regulations. Each farmer will irrigate his farmland with the same number of athars at each dawran. Furthermore, the same sequence of exctracting water shares is maintained during the irrigation cycles (Norman et al., 1998b).

Water and land shares can be sold or leased. This is often done to finance falaj service and maintenance or for charity, e.g. to be used for mosques and Islamic schools.

Scheduling of Irrigation

As mentioned previously, for most aflaj in Oman, the day is divided into night-time badda and daytime badda; each badda typically equals 24 athars. The daytime badda begins at sunrise and ends at sunset, while the night-time badda lasts from sunset until sunrise. Farmers use a wide range of methods to determine the length of an athar representing the water share for a farmer. While farmers have started relying on watches nowadays, traditionally the timing of irrigation was determined by using sundials during the day and stars at night.

A typical traditional sundial used in northern Oman consists of a simple stick placed vertically on a flat rectangular area. 24 stones are carefully spaced to represent 24 daytime athars, with early and late daytime stones further apart from each other than stones representing midday athars. The stones are put in one line, in east-west direction. In order to adjust to the seasons, such a system typically has three lines, one for summer, one for fall and one for winter.

At night, farmers use stars to schedule irrigation and determine the length of an athar. Specific sets of stars are used for determining time, varying from one village to another. Farmers measure one athar by the time between the rise of (a) particular star(s) to the rise of the following star(s).

Nowadays, in many aflaj farmers use watches to determine the timing of water distribution. They count 30 minutes for each athar, so the full day is equal to 48 athars. Interestingly, when the modern watch was first introduced to Oman, a so-called sunset timing system emerged in which farmers adjusted the watch to 12:00 at sunset everyday. Since the late 1960s and early 1970s, farmers have gradually been replacing this system with the “normal” meridian time system.

Maintaing Equity in the Falaj Water Distribution System

In the traditional sundial and star method, because of the variation of the length of day and night throughout the year, farmers may have more or less water per athar. In northern Oman, where most of the aflaj exist, athar varied in length between 20 and 40 minutes. For example, during winter farmers irrigating at night will receive more water than farmers irrigating during the day, and vice versa for summer. The scheduling of irrigation using the stars to determine the timing can also be inaccurate.

In order to address these inequities, ancient farmers came up with various solutions. For example, they alternated the irrigation between day and night from one to the next dawran. Another method, which was mainly used in central Oman, was to simply design dawrans with an odd number of badas. This automatically results in alternation between day and night irrigation for the various farmers (Wilkinson, 1977).

In large aflaj systems, the stream of water of the main channel is divided into several sub-streams, depending on the size of the falaj and its flow rate (Figure 6). The amount of flow in each sub-canal is set to be equal. Farmers can irrigate from one stream or more than one stream at the same time. The farmer who irrigates using the main stream will receive the same amount of water as a farmer who irrigates from more than one sub-canal. Aflaj with a stable flow are usually divided permanently into major sub-streams. Each stream will be devoted to a specific land area. The dawran is not necessarily fixed for the entire falaj, but each major stream may have its own dawran.

During a drought a wide range of adaptation strategies exist and are applied, such as adjusting the dawran or reducing the number of sub-streams. For example, in Falaj al-Dariz the main stream is permanently divided into two streams, one with a dawran of 9 days, the other with a dawran of 10 days, reflecting the different soil types of the irrigated land. During times of drought, this falaj is united in one stream and the dawran is increased to 19 days. In Falaj Al-Ghayzayn, the falaj is also normally divided into two streams, both with a dawran of 7 days. During dry spells, farmers irrigate from one stream only. Thus, the dawran is doubled from 7 days to 14 days. In very low flow rates, the dawran is extended to 28 days (Birks and Letts, 1977). Wilkinson (1977) further reported that the dawran is altered seasonally in some aflaj to meet the changing requirements of summer and winter irrigation.

In Falaj Al-Farsakhi, farmers adopted a very simple method to ensure equitable distribution of water shares. The falaj water rights are divided into eight full days. Each day is further divided between groups of owners, from 4-8 owners in each group. While each group irrigates on the same day during each dawran, the order of irrigation is reversed for each dawran.

Furthermore, it is a common practice in small aflaj systems that farmers store some water in a big tank in order to maintain a stable flow rate throughout the year. The time for storing water is included in the time share of each farmer. It has been observed that water is only stored in this system when the water flow of the falaj becomes unmanageable. This method proved to reduce the time required for irrigation and increase its efficiency. If a farmer cannot finish all the stored water before the irrigation time of the next farmer starts, his remaining water will be allocated to the succeeding farmer.

Figure 6. Flow division in aflaj systems.

Conclusions

Agricultural production in Oman is almost fully dependent on irrigation, and more than one-third of the water used for irrigation is supplied by the aflaj. Aflaj are also very important systems that allow farmers to control and mitigate drought. Despite this, more than one-quarter of the aflaj have fallen into dis-use due to many social and technical problems.

At the same time, there is a trend that technical knowledge about the aflaj, including the traditional time measurement methodologies and aflaj construction and management, remains mostly with the older generation. Thus, the knowledge needed to manage and maintain the aflaj is slowly disappearing.

Another difficulty is that traditional ways of determining the timing for irrigation are complicated and differ from one aflaj to another. Particularly, the older generation resists the adoption of modern methods to measure time intervals.

The government in its efforts to rehabilitate the aflaj should thus not only focus on utilizing new materials and rebuilding structures, but should particulary aim to improve and modernize the management of the water-share system. One important aspect would be to standardize all existing traditional water-share units by converting them to one standard time unit. Another aspect is to ensure that the water rights in all aflaj of Oman are documented and regularly updated. This would require that each falaj keeps its own records about water right holders and their share and timing of water.

References

Abdel Rahman, H.A. and A. Omezzine (1996) "Aflaj Water Resources Management: Tradable Water Rights to Improve Irrigation Productivity in Oman" Water International 21(2): 70-75.

Abdel Rahman, H.A. and I. M. Abdel-Magid (1993) "Water Conservation in Oman" Water International 18(2): 95-102.

Al-Abri, B. and Al-Bayan Fi Badh (1980) Aflaj Oman (in Arabic), Golden Printing Press, Muscat, Oman.

Al-Ghafri, S. Abdullah, Inoue, Takashi, Norman, and W. Ray (1999) "Water Distribution in Aflaj Irrigation Systems of Oman" In: Proceedings of the annual meeting of the Japanese Society of Irrigation Drainage and Reclamation Engineering (JSIDRE), August 1999, University of Tokyo and Miji University, Tokyo.

Al-Ghafri, Abdullah S., Norman, W. Ray, Inoue and Nagasawa, Tetuaki (2000a) "Traditional Irrigation Scheduling in Aflaj Irrigation Systems of Oman, Case Study of Falaj Al-Hageer, Northern Oman. " In: Proceedings of The First International Symposium on Qanat, 8-11May in Yazd, Iran.

Al-Ghafri, Abdullah S., Inoue, Takashi and Nagasawa, Tetuaki, (2000b) "Aflaj Irrigation Systems of Oman, The Way of Water Distribution" In: Proceedings of The XIV Memorial CIGR World Congress 28 February – 1 December 2000 in Tsukoba, Japan.

Al-Marshudi, A. (1995) "Operation of the Aflaj System" Traditional Agriculture and Fishing in the Sultanate of Oman, SQU, Modern Color Printers, Legal Deposit No. 251/95: 5-10.

Al-Saleemi, Mahfoodh, Abdel Fattah, Nabeel (1997) Administration and Organization of Aflaj in the Sultanate of Oman, Analytical Study (in Arabic), Institute of Public Administration, Oman.

Birks, J.S. and S.E. Letts (1977) "Diqal and Muqaydah: Dayimg Oases in Arabia" Tijdschrift voor Econ.en Soc. Geograpie 68(3): 145-151.

Costa, P.M. and T.J.Wilkinson (1987) "The Water Supply of Early Islamic Sohar" Ministry of National Heritage and Culture, Sultanate of Oman, The Journal of Oman Studies 9, Chapter 4: 42-80,.

Cressey, G.B. (1958) "Qanat, Karez and Foggaras" Geographical Review 48: 27-44.

Ministry of Information (1997) Oman 1997, Muscat, Oman.

Norman, W. R., Shayya, W. H., Al-Ghafri, Abdullah S., (1998a) "Irrigation Water Costs and Management Practices Among Farms in Northern Oman" Journal of Scientific Research, Agricultural Sciences (3): 1-8.

Norman, W. R., Shayya, W. H., Al-Ghafri, Abdullah S., and McCann, I.R., (1998b) "Aflaj Irrigation and On-farm Water Management in Northern Oman" Irrigation and Drainage Systems 12: 35-38.

Sekai No Kangai to Haisui Kikakuiinkai (1995) Sekai No Kangai to Haisui; Mizu to Midori no Tameni (in Japanese), Iee no Hikari Kyoukai Hen publisher, Japan.

Sutton, S. (1984) "The Falaj a Traditional Co-Operative System of Water Management" Waterlines 2(3).

Wahby, H. and S. Al-Harthi (1995) "General Controlled Irrigation Systems for Optimum Use of Water in falaj Keed at Bahla Saud" In: Proceedings of Sultanate of Oman International Conference on Water Resource Management in Arid Countries, Ministry of Water Resources, Oman: 9-15.

Wilkinson, J.C. (1977) Water and Tribal Settlement in Southeast Arabia: a Study of the Aflaj of Oman, Oxford, Clarendon Press.

Contributing Authors

Zafar Adeel
Director
United Nations University
International Network on Water,
Environment and Health
(UNU-INWEH)
175 Longwood Rd South, Suite 204
Hamilton, Ontario L8P 0A1
Canada

Abdullah S. Al-Ghafri
Associate Researcher
Department of Soils, Water &
Agricultural Engineering
College of Agricultural and Marine
Sciences
Sultan Qaboos University
Al-Khod 123, Oman

Najib M. Al-Ghulaibi
Water Component Coordinator
Agricultural Research and
Extension Authority (AREA)
NARS
Yemen

Mondher Fetoui
Institut des Régions Arides (IRA)
4119 Medenine, Tunisia

Faisal Farooq Khan
WWF-Pakistan
Programme Development Division
Islamabad, Pakistan

Iwao Kobori
Senior Programme Advisor
Environment and Sustainable
Development Programme
United Nations University
53-70, Jingumae 5-chome,
Shibuya-ku
Tokyo 150-8925, Japan

Luohui Liang
Academic Programme Officer
Environment and Sustainable
Development Programme
United Nations University
53-70, Jingumae 5-chome,
Shibuya-ku
Tokyo 150-8925, Japan

Keiko Oshima
Department of Asian Area Studies
Graduate School of Daito Bunka
University
Japan

Mohammed Ouessar
Institut des Régions Arides (IRA)
4119 Medenine, Tunisia

Monghi Sghaier
Institut des Régions Arides (IRA)
4119 Medenine, Tunisia

Sun Qingwei
Assistant Research Professor
Cold and Arid Regions
Environmental and Engineering
Research Institute
The Chinese Academy of Sciences
Lanzhou 730000, P.R. of China

Wang Tao
Cold and Arid Regions
Enviromental and Engineering
Research Institute
The Chinese Academy of Sciences
Lanzhou 730000, P. R. of China

Joshka Wessels
Amsterdam Research Institute for
Global Issues and Development
Studies (AGIDS)
University of Amsterdam
The Netherlands

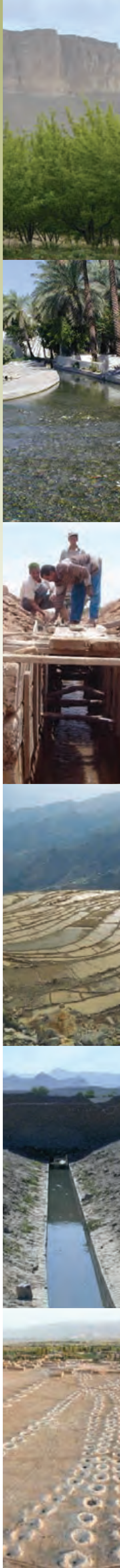
UNU Desertification Series No. 8

What Makes Traditional Technologies Tick?
A Review of Traditional Approaches for Water Management in Drylands

Edited by Zafar Adeel, Brigitte Schuster and Harriet Bigas

Dryland dwellers face the significant challenge of managing their scarce water resources sustainably, exacerbated further by global drivers such as climate change, land degradation, biodiversity loss and changes in vegetation cover, as well as pressures from demographic, economic and political processes. Over the centuries, dryland communities have developed traditional methods of harvesting and manging water which have ensured long-term sustainability of this resource.

This book reviews different approaches and techniques for traditional water management in drylands and how these can be used to cope with today's challenges. The case studies from different parts of the world identify successes and lessons learned from communities that are continuing to use traditional water management techniques. These case studies outline how traditional approaches can be applied effectively to meet the future water needs of the world's dryland communities.



UNITED NATIONS UNIVERSITY
UNU-INWEH
International Network on Water, Environment and Health

ISBN 92-808-6003-8